Report No. CG-D-09-96

SIDE-BY-SIDE SEAKEEPING TESTS OF THE USCGC PADRE (WPB 1328) AND THE USCGC SHEARWATER (WSES 3)

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16. Abstract

This report contains the results of a limited set of side-by-side seakeeping tests using the USCGC PADRE (WPB 1328), a semi-planing monohull, and the USCGC SHEARWATER (WSES 3), a surface effect ship (SES). The objective was to obtain data that would allow the ride quality of the two boats to be compared.

A short side-by-side test drifting in beam seas was followed by two sets of underway tests. Underway tests were performed at 15 knots in 3.2 ft. seas, and at 18 knots in 3.7 ft. seas, at five headings to the sea: head, bow, beam, quartering, and following. A waverider buoy was used to measure sea state. A Humphrey, Inc. motions package was installed in each boat. Roll, pitch, and yaw angle, roll, pitch and yaw rate, and heave, surge, and sway acceleration measurements were recorded and analyzed. The results of the analysis are presented in graphs and tables.

Based on limited data taken at moderate speeds in low sea states, there was little difference between the motions of these two patrol boats while underway. The monohull rolls much more than the off-cushion SES while drifting in beam seas.

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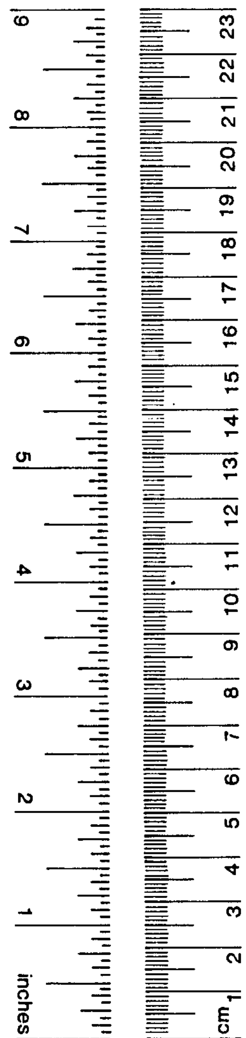
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

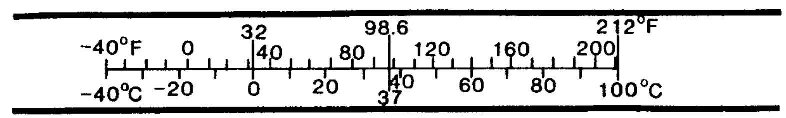


TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES

EXIBITS

LIST OF TABLES

LIST OF TABLES

INTRODUCTION

Coast Guard interest in the comparative performance of various patrol boat types dates back to the seventies, when paper studies (1)* evaluated the relative ability of different vessel types to perform various Coast Guard missions. The interest was prompted by the need to evaluate the performance of candidate craft prior to future acquisition in order to assure that the craft would meet the needs of the service. The paper studies gave way to full scale test and evaluation as the time for patrol boat acquisition drew near.

The first Coast Guard test and evaluation of a candidate Surface Effect Ship (SES) took place in 1980 (2). Subsequently, this Bell Halter crew boat was outfitted as a patrol boat, the USCGC DORADO (WSES 1), for the purpose of performing an operational evaluation (3). Three SES patrol boats were acquired and placed in commission in 1982 and 1983 for drug interdiction operations out of Key West, Florida. One of these patrol boats was the USCGC SHEARWATER (WSES 3).

The Coast Guard started to acquire a significant fleet of Island Class, 110 foot, monohull, patrol boats in 1985. One of these boats, the USCGC PADRE (WPB 1328), was commissioned in 1989. Although a test and evaluation of an Island Class boat was performed in 1987 (4), it was natural to plan a side-by-side seakeeping evaluation of an SES and one of the newly acquired monohulls. This would allow a direct comparison of the ride qualities of the two boat types to be made under identical conditions of wind and waves.

An abbreviated set of side-by-side seakeeping tests was conducted near Key West, Florida on 31 March 1992 using the USCGC PADRE (WPB 1328) and the USCGC SHEARWATER (WSES 3). Authorization for the tests is contained in a line item in the Fiscal Year 1992 Budget Sheet. Planning for the tests is documented in reference (5).

TEST OBJECTIVE

The objective of these tests was to obtain data that would permit a quantitative comparison to be made of the ride qualities of an in-service 110 foot WSES and a newly acquired 110 foot WPB. The data may prove useful for future comparative design studies. To fulfill this objective, side-by side seakeeping tests were performed at different speeds and five headings to the sea. The tests were performed at sea in an area of south of Key West, Florida.

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* Note: The numbers in parentheses refer to references on page 11 of the report.

DESCRIPTION OF THE PATROL BOATS

The USCG Island Class patrol boat is a semi-planing craft. The design is based upon a 33 meter, Vosper Thornycroft, U.K. parent patrol craft. Various versions of the design are serving in Venezuela, Qatar, Abu Dhabi and Singapore. The USCG version was built in the U.S. at Bollinger Machine Shop and Shipyard, Lockport, LA. It was primarily designed to perform Enforcement of Laws and Treaties (ELT) patrols, but the craft is capable of performing the full range of USCG WPB functions. It is the first class of Coast Guard patrol boats to be equipped with anti-roll stabilizers. Figure 1 is a profile drawing of this B class WPB. A lines drawing is not included because the lines are proprietary. A detailed description of the patrol boat is given in reference 4. Table 1 contains the principal characteristics of the vessel.

Note that the USCGC Padre had a test displacement of 120 l. tons. This seems a bit low considering the fact that the light weight displacement of the patrol boat is 117 l. tons. However, the test log indicates that the draft was 5'-3" fwd. and 7'-2" aft. This corresponds to a displacement of 120 l. tons on the curves of form for the patrol boat. The boat was not inclined, so the GM was not measured at the time of the tests.

The Sea Bird Class patrol boat is a high speed SES. The design is based upon a 110 foot Bell Halter crew boat. The USCG version was built in the U.S. at Bell Halter, Inc., New Orleans, LA. The Sea Bird Class patrol boats were the first class of advanced marine vehicles in the Coast Guard inventory. These boats were also acquired to perform ELT patrols, but from time to time have performed the full range of USCG WPB functions. Figure 2 is a profile drawing of the boat. A lines drawing is not included because the lines are proprietary. A detailed description of the craft is given in reference 3. Table 1 also contains the principal characteristics of this vessel.

The test log indicates that the draft was 7'-2' fwd. and 9'-6" aft. This would correspond to an off cushion condition. The USCGC Shearwater was not equipped with a ride control system. The only WSES to be so equipped was the USCGC Sea Hawk (WSES-2). The boat was not inclined, so the GM was not measured at the time of the tests.

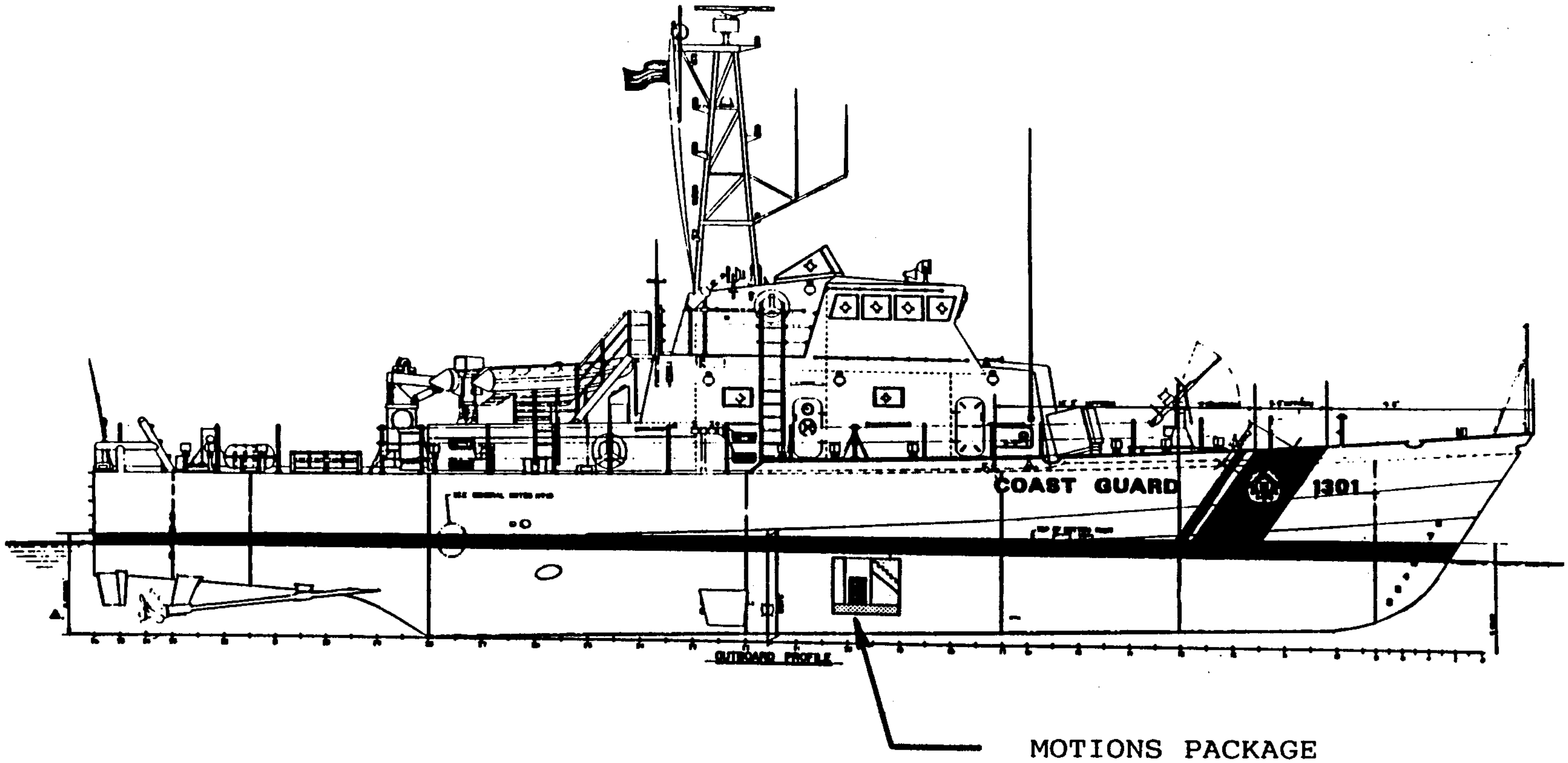

FIGURE 1. OUTBOARD PROFILE OF THE USCGC PADRE (WPB 1328).

TABLE 1

PRINCIPAL CHARACTERISTICS

	110 Ft. WPB	110 Ft. WSES
Length Overall	110 Ft. 0 In.	109 Ft. 2 In.
Length Between Perpendiculars	104 Ft. 1/2 In.	93 Ft. 6 In.
Beam (Maximum)	21 Ft. 1 In.	39 Ft. 3 In.
Depth, Molded (Deck Amidships)	10 Ft. 11 1/4 In.	15 Ft. 1 In.
Draft (Mean)	6 Ft. 5 1/4 In.	7 Ft. 6 In. (Off Cush.) 3 Ft. 0 In. (On Cush.)
Displacement (Test)	120 L. Tons	134 L. Tons
Material, Hull	Steel	Aluminum
Deck	Aluminum	Aluminum
Main Engines (2) Each	Paxman (16RP200) limited to 3000 HP	Detroit Diesel (16V 149T) 1800 HP
Speed (Maximum)	Approx. 30 Knots	Approx. 30 Knot

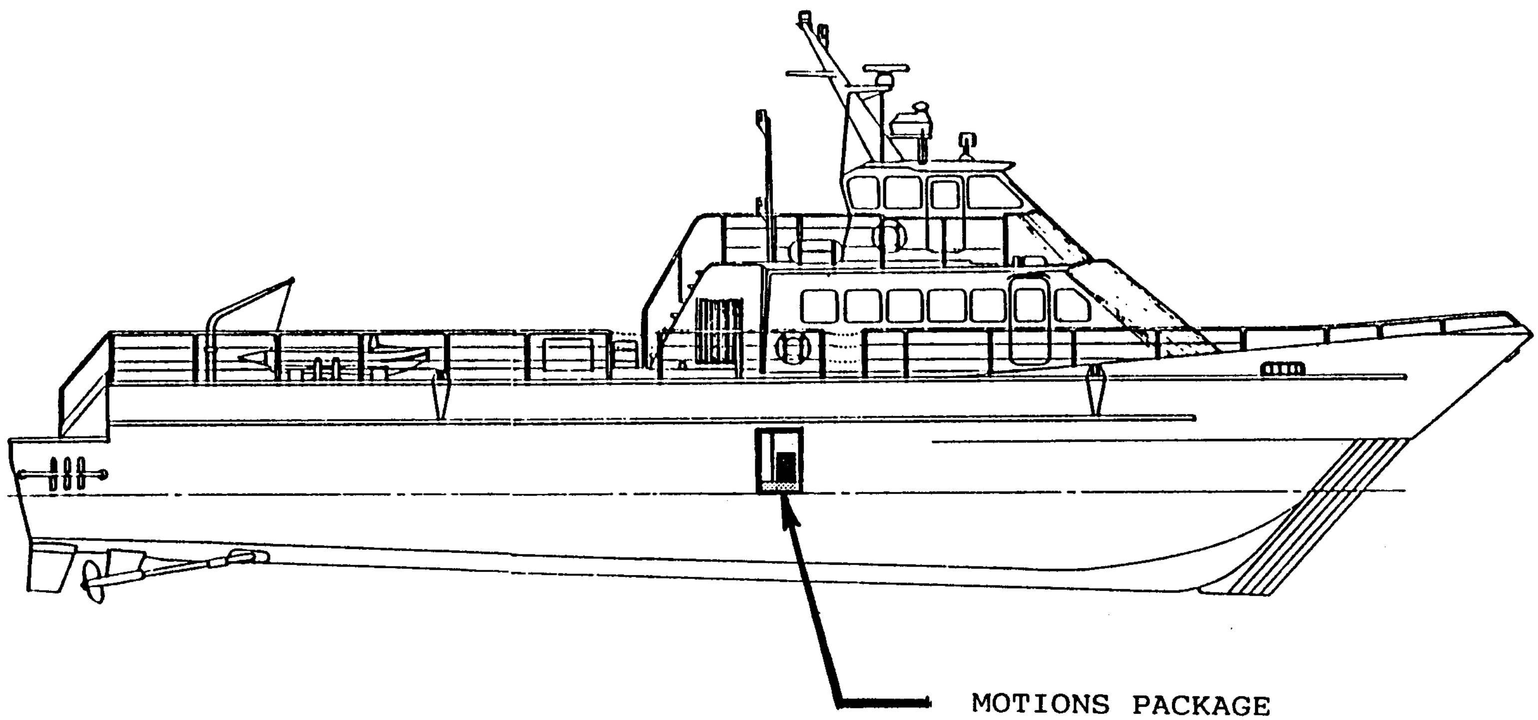

FIGURE 2. OUTBOARD PROFILE OF THE USCGC SHEARWATER (WSES 3).

TEST INSTRUMENTATION

A Humphrey, Inc. model CF18-0901-1 motions measuring package was installed on each boat. The output functions from these packages include three axis position, three axis acceleration, and three axis angular rate measurements. The gyroscopes in the packages are electrically caged and uncaged. Acceleration measurements can be made with respect to either the body axis of the package or a stabilized vertical axis. Rate measurements are made continuously with respect to the body axis of the package. The Humphrey motion package was rigidly fixed aboard each patrol boat as indicated in Figures 1 and 2. The motion packages were calibrated before the tests began. The output of the motions packages were recorded on magnetic tape using TEAC RD-200T PCM data recorders. Each motions package was equipped with its own data recorder. The motions recorded were well within the specified ranges for the motions packages used.

A Datawell Waverider buoy was deployed during the tests to measure the wave surface elevation as a function time. The Waverider buoy was free to drift. A 22 pound (10 kg) weight was attached to the mooring eye of the buoy. This is recommended by the manufacturer to prevent large roll and pitch angle excursions which would contaminate the wave elevation measurements. The transfer function for the Waverider is does not vary with frequency for the range of wave frequencies encountered. The wave rider is calibrated periodically and remains in calibration. The Waverider transmitted the wave elevation data to a receiver aboard the SES.

DESCRIPTION OF TESTS

The tests were performed south of Key West, Florida in the Straits of Florida (latitude 24 degrees, 11.77 minutes, longitude 81 degrees, 55.05 minutes) on 31 March 1992. Three sets of seakeeping tests were completed satisfactorily. A waverider buoy was deployed, and wave elevation measurements taken, for 20 minutes before the first and third sets of tests.

The first set of tests was performed side-by-side, under way with no way on, in beam seas. The tests were of short duration (less than 5 minutes). The USCGC PADRE (WPB 1328) experienced a significant roll angle build-up (up to plus or minus 22 degrees) almost immediately. The USCGC SHEARWATER (WSES 3) experienced modest roll angles (plus or minus 6 degrees) at the same time.

The second set of side-by-side tests was performed under way at approximately 18 knots at a series of headings with respect to the seas. The patrol boats maintained course and speed, and data were recorded, for approximately 12 minutes on each heading. The headings were: head seas (240 degrees), bow quartering seas (285 degrees) beam seas (330 degrees), stern quartering seas (15 degrees), and following seas (60 degrees).

The third set of side-by-side tests was performed under way at approximately 15 knots at a series of headings with respect to the seas. Once again, the patrol boats maintained course and speed, and data was recorded for approximately 12 minutes on each heading. The headings were: head seas (260 degrees), bow quartering seas (305 degrees), beam seas (350 degrees), stern quartering seas (35 degrees), and following seas (80 degrees). Note that there was a 20 degree shift in the wind and waves between the second set of tests, run in the morning, and the third set of tests, run in the afternoon. Additional tests were planned, but had to be canceled due to calm weather.

Baseline recordings were taken on all data channels at dockside before the tests started in the morning and after the tests finished in the afternoon. The following data were collected and recorded on magnetic tape during each test: roll, pitch, and yaw angle, roll, pitch, and yaw rate, and heave, surge, and sway acceleration.

DATA REDUCTION

A Hewlett Packard (HP) 35660A Dynamic Signal Analyzer was used to generate two Wave Energy Density Spectrum plots by processing the data taken from the two Waverider buoy deployments. The modal wave frequency and the modal wave energy density can be determined from these graphs. The bandwidth of the spectrum can also be estimated from these plots.

Data analysis was performed using an HP Series 200 computer. The nine channels of ship motion information recorded on each of the TEAC Data Recorders on board the 110 Ft WPB and 110 Ft WSES, as well as, the Waverider wave elevation information were played back through an HP 3497 Data Acquisition/Control System and an HP 9920 computer. This system allows offset voltages, calibration factors and sampling rates to be inserted into a software program GENSES (6), where digitization and conversion to engineering units is accomplished. GENSES is one of five programs written (6) to aid in the analysis and evaluation of ship motion and performance data.

Another program, GENPLT, from the same suite of programs (6), was used to perform a statistical analysis of the data. A general description of how this program analyzes data is presented in Appendix A. The program searches for the maximum peaks and the minimum troughs between zero crossings in any given data channel. It converts these extreme values into absolute values which it labels "peaks". It then performs a statistical analysis of these peaks. Among other things, GENPLT will plot the data, list the value of the peaks found (in descending order of magnitude), and print the following statistics: the average of the 1/10 highest peaks, the average of the 1/3 highest peaks, the arithmetic mean of the "peaks", and the variance of the peaks.

PRESENTATION OF THE DATA

Wave energy density spectra, generated from the data taken during the two Waverider buoy deployments are presented in Figures 3 and 4. Figure 3 is a graph of the Wave Energy Density (Ft^2/Hz) versus Frequency (Hz) for the morning deployment. This data was taken before the first set of tests. Since the first set of tests were of short duration, this spectrum is also considered to be representative of the sea state for the second set of tests. Figure 4 is a similar graph for the afternoon deployment. Note that these are point spectra. Information about the direction of the wind and waves cannot be deduced from either the Waverider buoy or these spectra. The modal point is indicated by an X, and the coordinates of the modal point are given in a box on each figure.

The results of the side-by-side tests, conducted with no way on, are presented in Figures 5 through 8. Figures 5 and 6 present the time history of the roll angle, for the duration of the test, for the USCGC PADRE and the USCGC SHEARWATER respectively. Figures 7 and 8 present the time history of the roll angle rate, for a period of a minute in the neighborhood of the start of the test, for the USCGC PADRE and the USCGC SHEARWATER respectively. These graphs contain all of the significant information obtained from these tests. Note that the scales vary from figure to figure. This is because the software package used automatically chose the scales based upon the range of the data to be plotted. The user had no influence on the choice of scales.

A summary of the information obtained in the side-by-side tests, conducted at 15 and 18 knots, is presented in graphical form in Figures 9 through 20.

These figures are polar coordinate plots. The vessel is assumed to be at the origin, or center, of the plot. It is travelling along the vertical diametral line in a direction from the point labeled FOLLOWING toward the point labeled HEAD. The plot is fixed in the vessel and moves with it. The sea are defined relative to the vessel. The seas approach the vessel along an inwardly directed radius from the points labeled HEAD, BOW, BEAM, QUARTER, FOLLOWING, QUARTER, BEAM, and BOW respectively. Symmetry about the vertical, FOLLOWING - HEAD, diametral line is assumed.

The motion characteristic (e.g. heave acceleration, roll angle, pitch angle, etc.), sea condition, and the speed of the vessel are given in the heading at the top of each plot. The legend gives the date of the test, the wind direction, and wind speed. It also indicates that the data for the USCGC PADRE is represented by x's connected by a dotted line, while the data for the USCGC SHEARWATER is represented by o's connected by a solid line.

Figures 9 through 14 present plots of the AVERAGE OF THE 1/3 HIGHEST: HEAVE ACCELERATION, ROLL ANGLE, and PITCH ANGLE PEAKS,

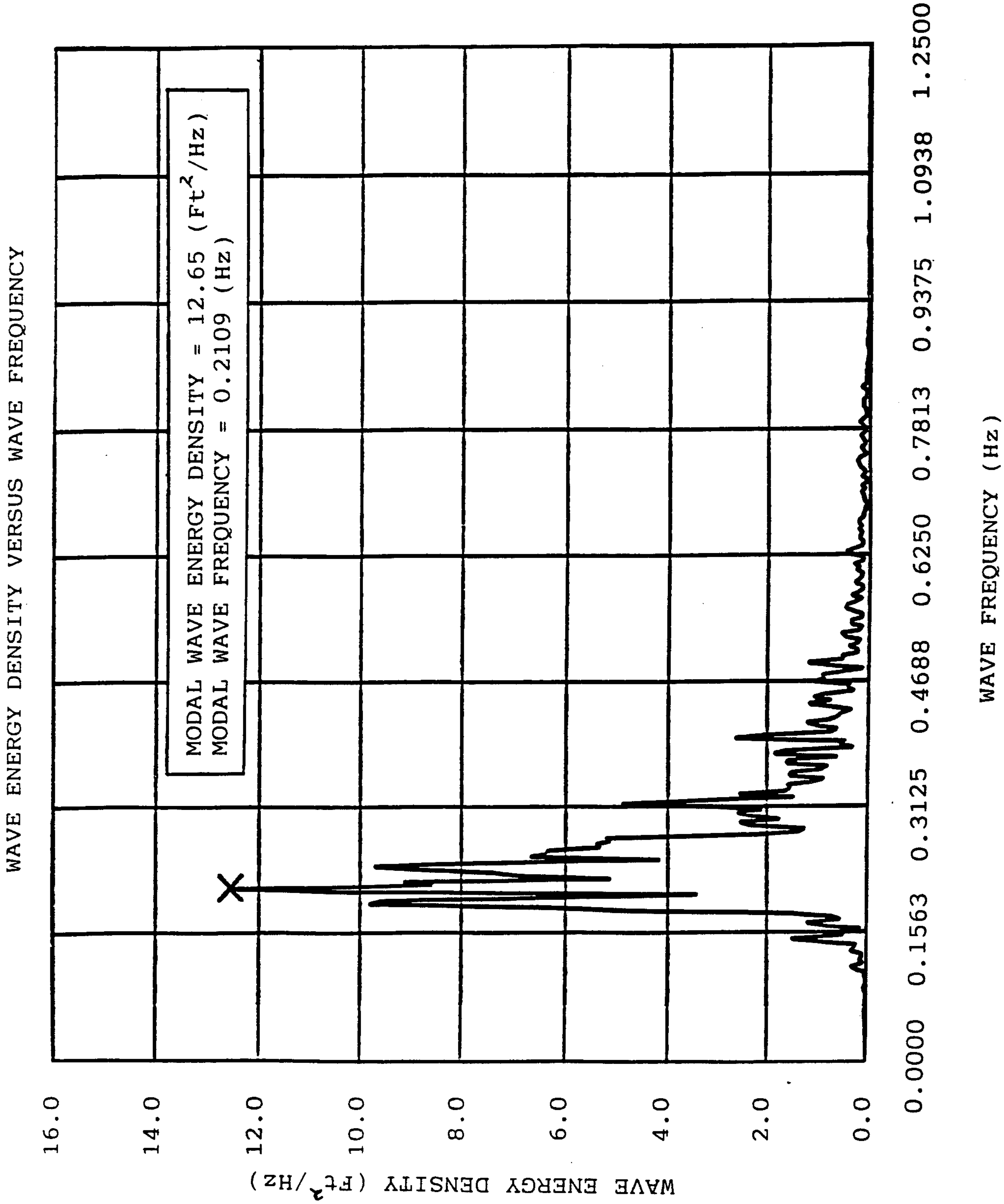

FIGURE 3. FIRST MEASURED WAVE ENERGY DENSITY SPECTRUM

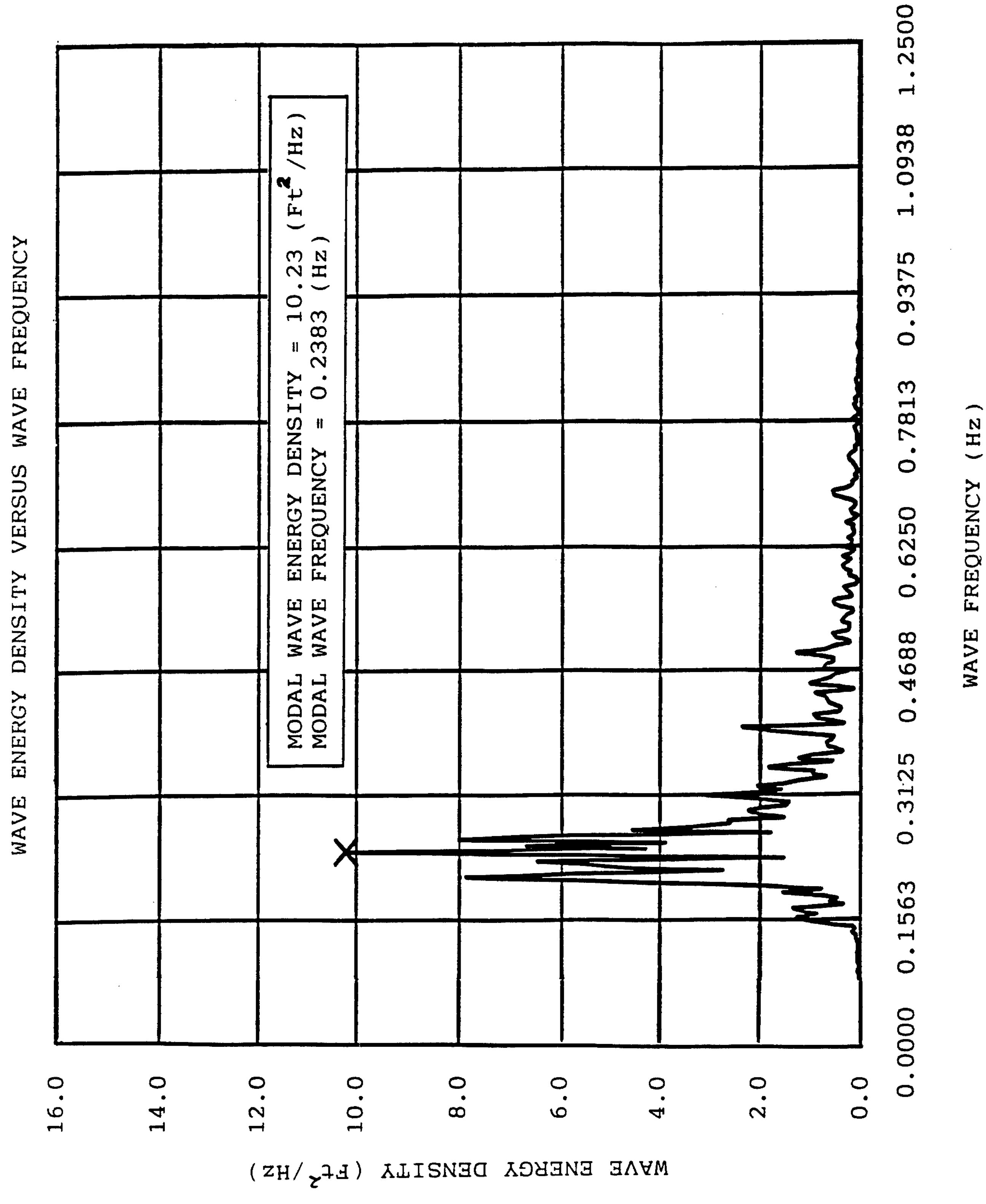

FIGURE 4. SECOND MEASURED WAVE ENERGY DENSITY SPECTRUM

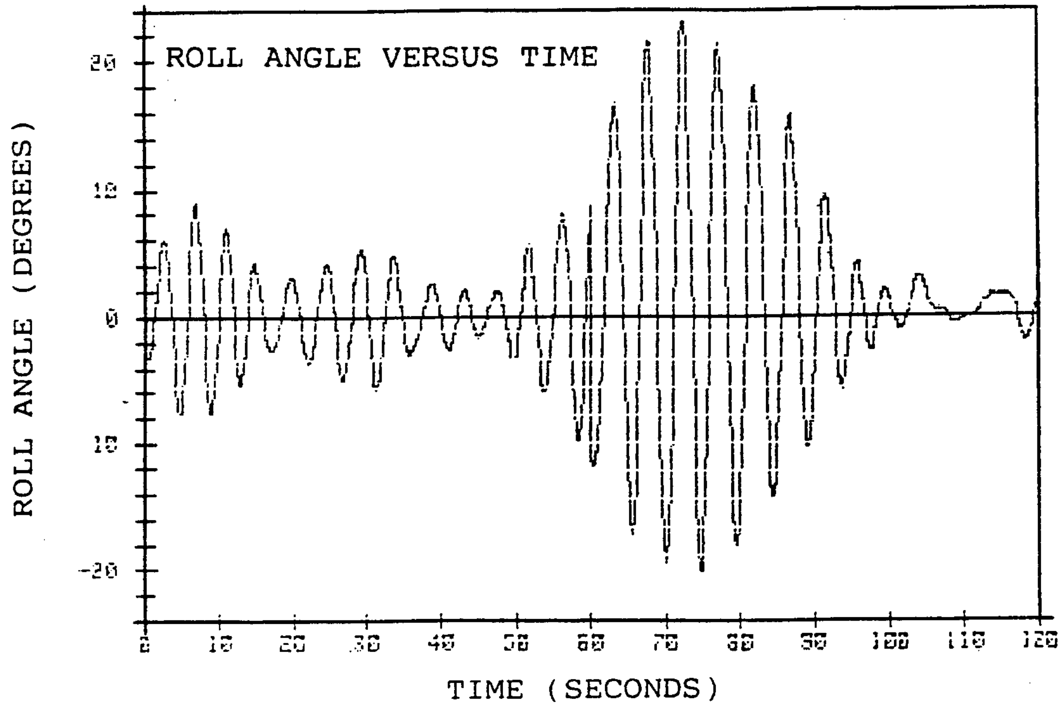

FIGURE 5. ROLL ANGLE TIME HISTORY FOR THE USCGC PADRE (WPB 1328). NO WAY ON.

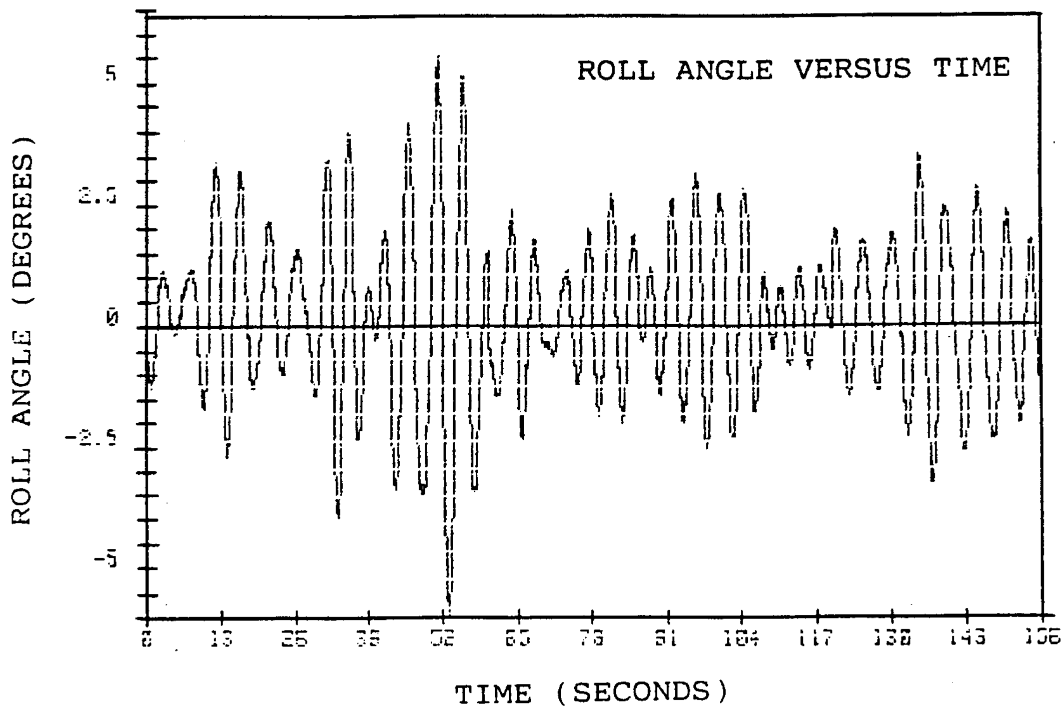

FIGURE 6. ROLL ANGLE TIME HISTORY FOR THE USCGC SHEARWATER (WSES 3). NO WAY ON.

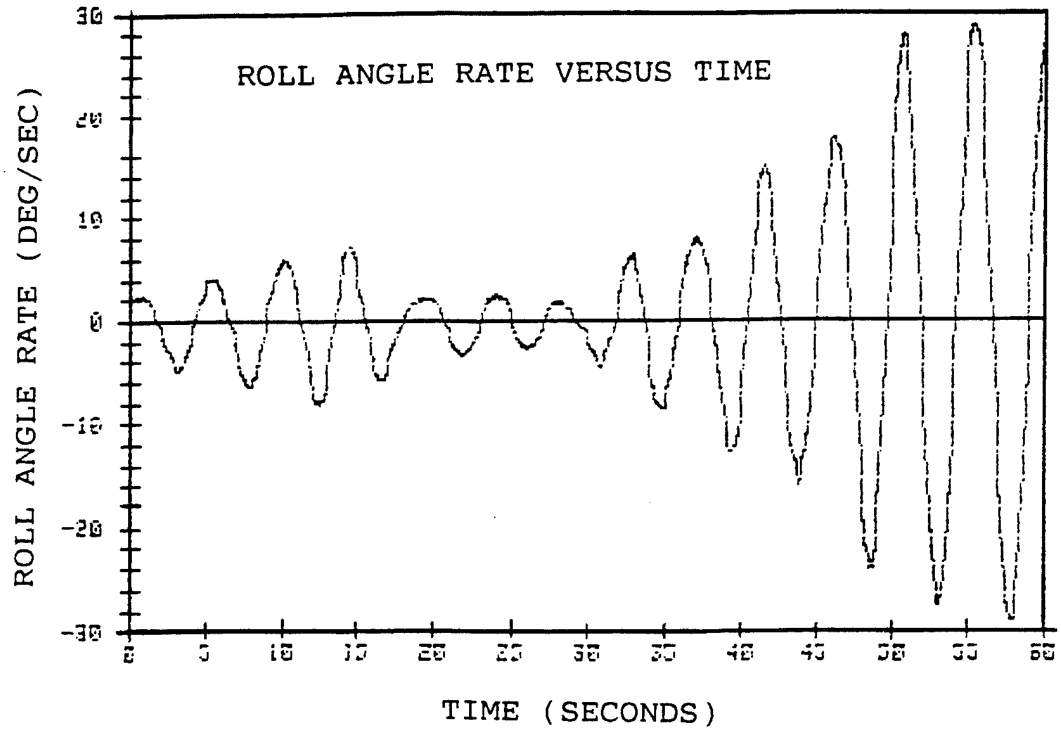

FIGURE 7. ROLL ANGLE RATE TIME HISTORY FOR THE USCGC PADRE (WPB 1328). NO WAY ON.

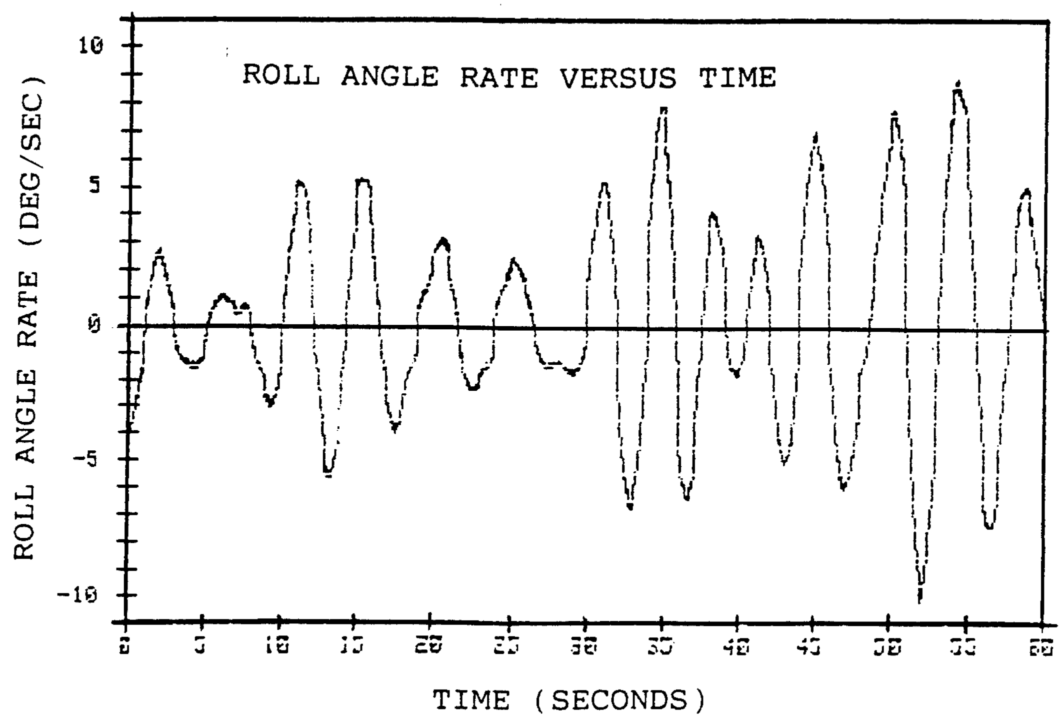

FIGURE 8. ROLL ANGLE RATE TIME HISTORY FOR THE USCGC SHEARWATER (WSES 3). NO WAY ON.

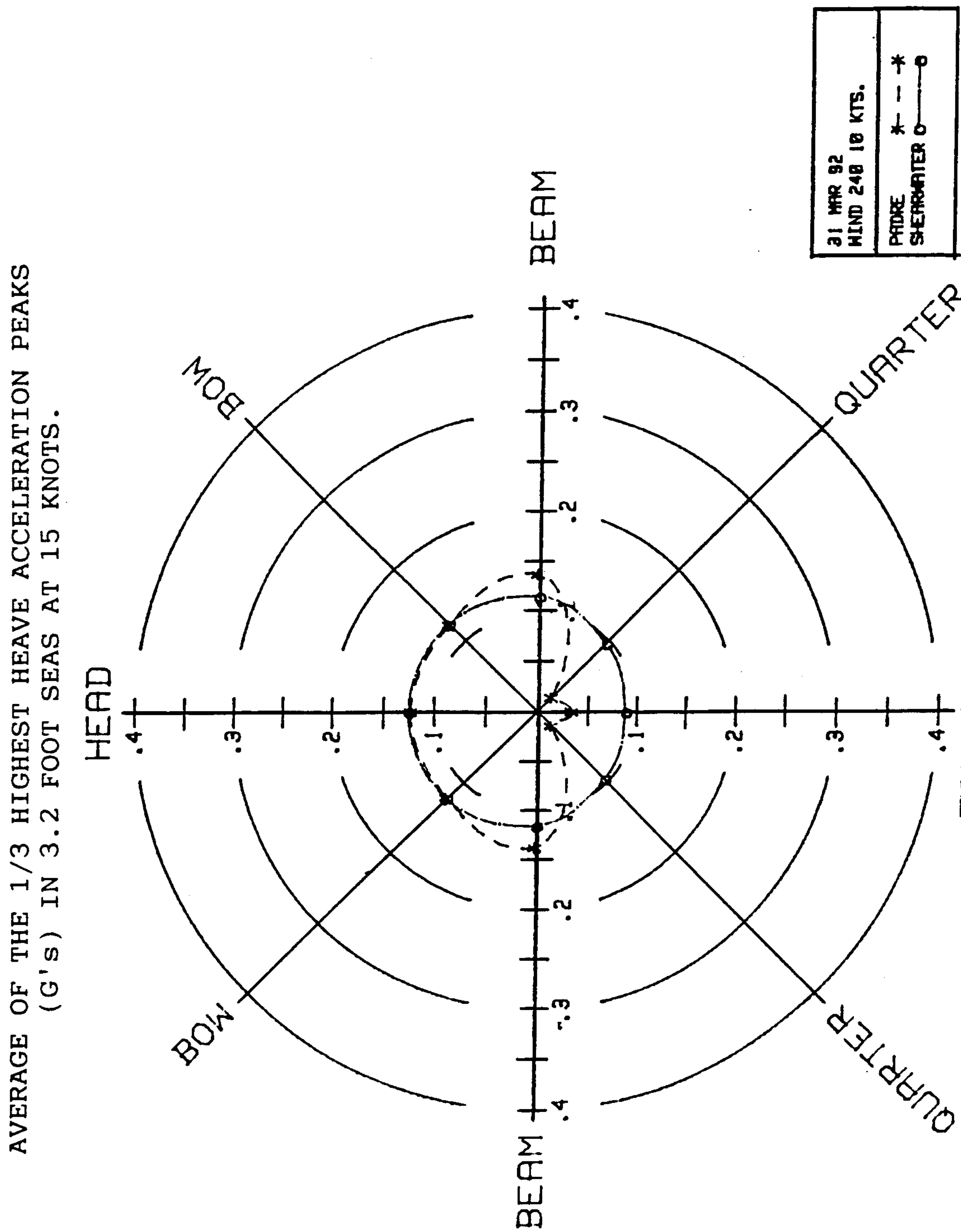

FIGURE 9. AVERAGE OF THE 1/3 HIGHEST HEAVE ACCELERATION PEAKS IN 3.2 FOOT SEAS AT 15 KNOTS.

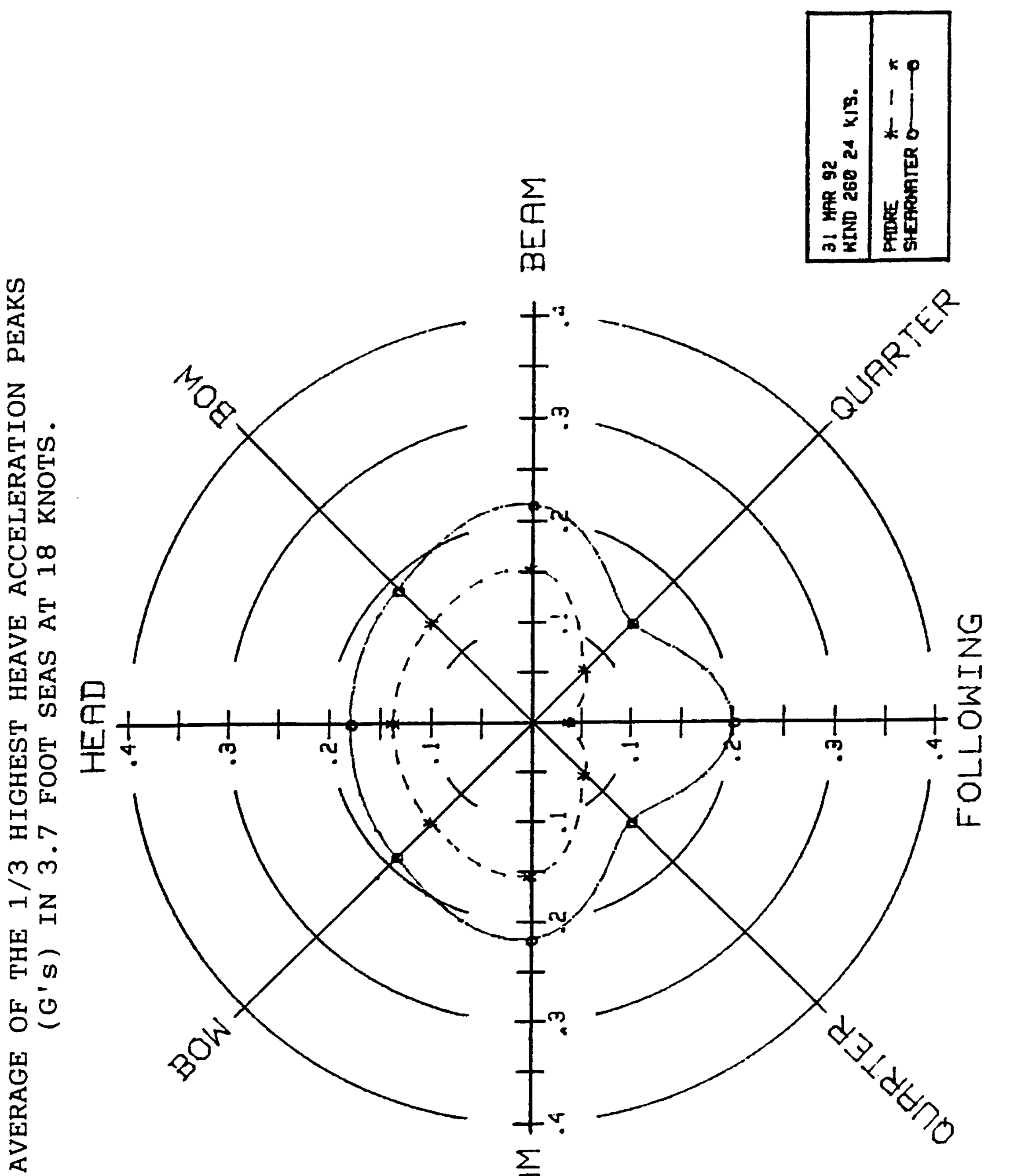

FIGURE 10. AVERAGE OF THE 1/3 HIGHEST HEAVE ACCELERATION PEAKS IN 3.7 FOOT SEAS AT 18 KNOTS.

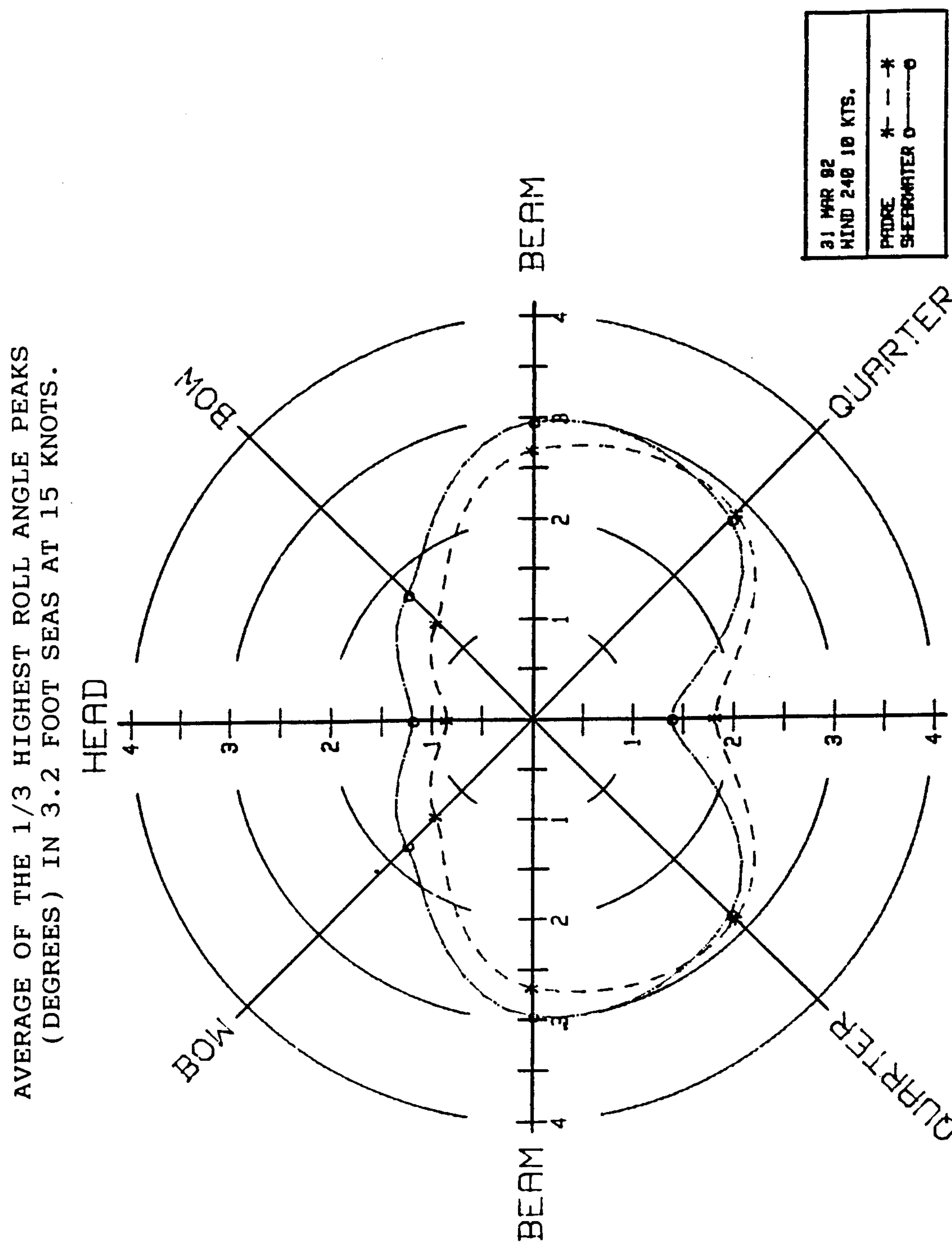

FIGURE 11. AVERAGE OF THE 1/3 HIGHEST ROLL ANGLE PEAKS IN 3.2 FOOT SEAS AT 15 KNOTS.

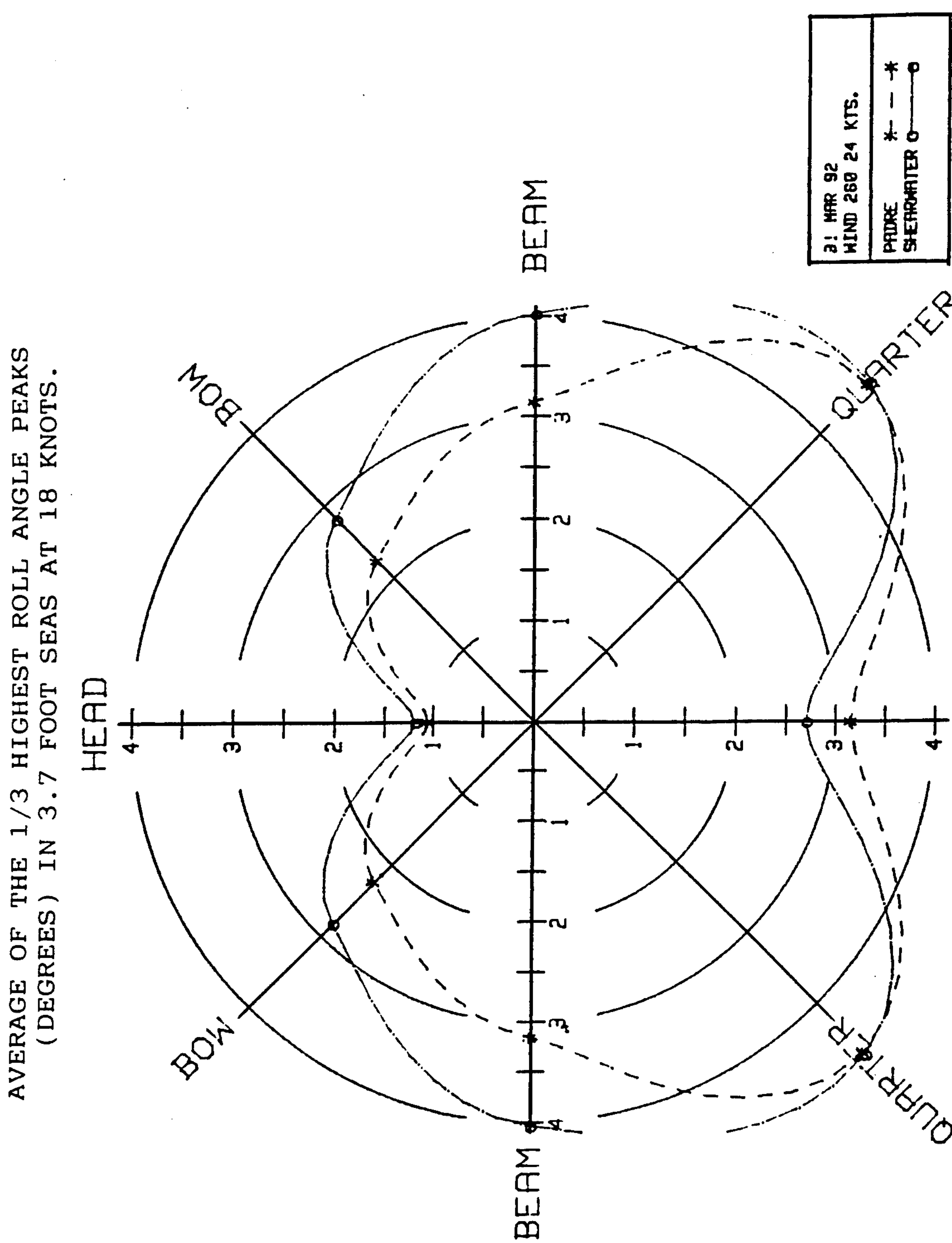

FIGURE 12. AVERAGE OF THE 1/3 HIGHEST ROLL ANGLE PEAKS IN 3.7 FOOT SEAS AT 18 KNOTS.

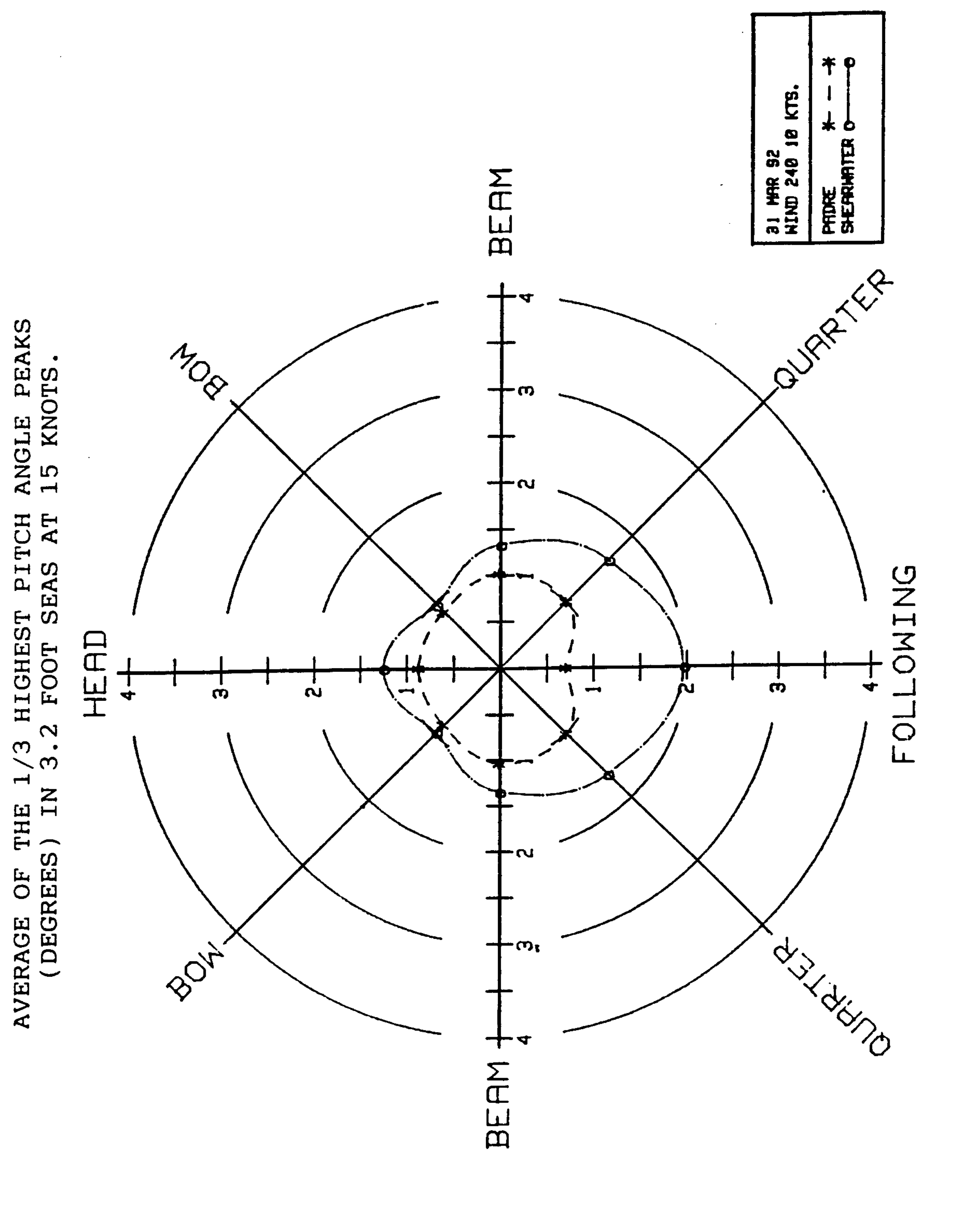

FIGURE 13. AVERAGE OF THE 1/3 HIGHEST PITCH ANGLE PEAKS IN 3.2 FOOT SEAS AT 15 KNOTS.

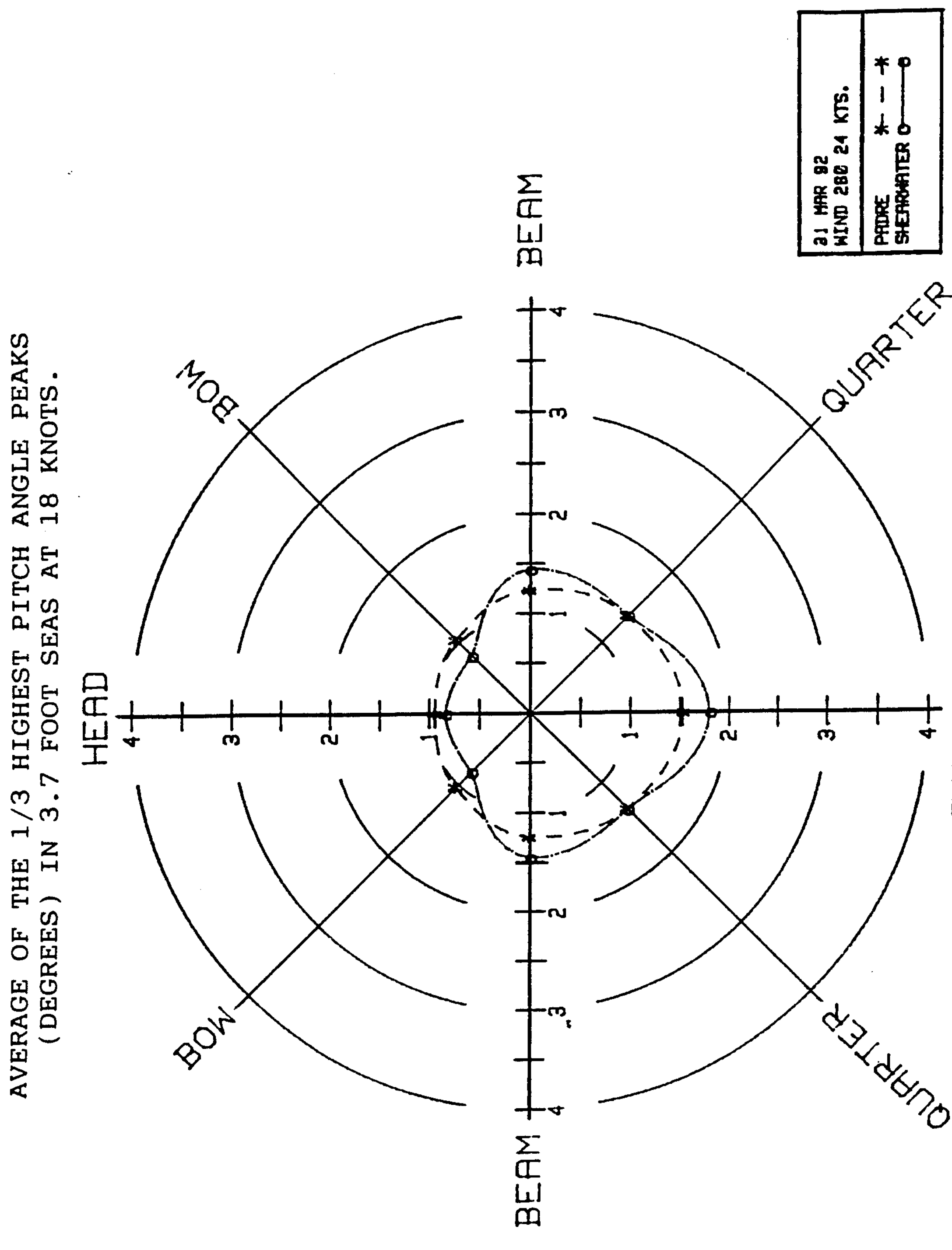

FIGURE 14. AVERAGE OF THE 1/3 HIGHEST PITCH ANGLE PEAKS IN 3.7 FOOT SEAS AT 18 KNOTS.

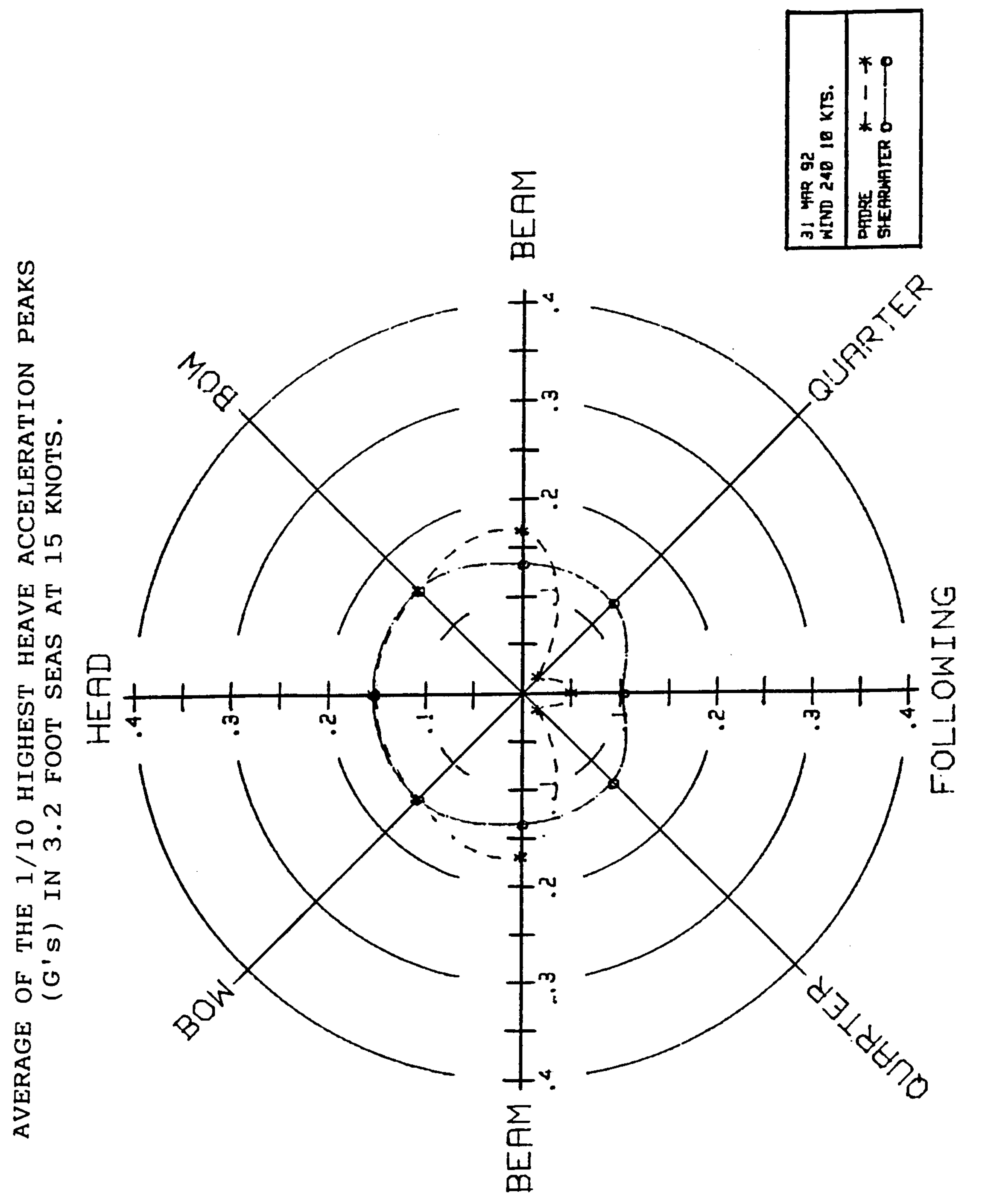

FIGURE 15. AVERAGE OF THE 1/10 HIGHEST HEAVE ACCELERATION PEAKS IN 3.2 FOOT SEAS AT 15 KNOTS.

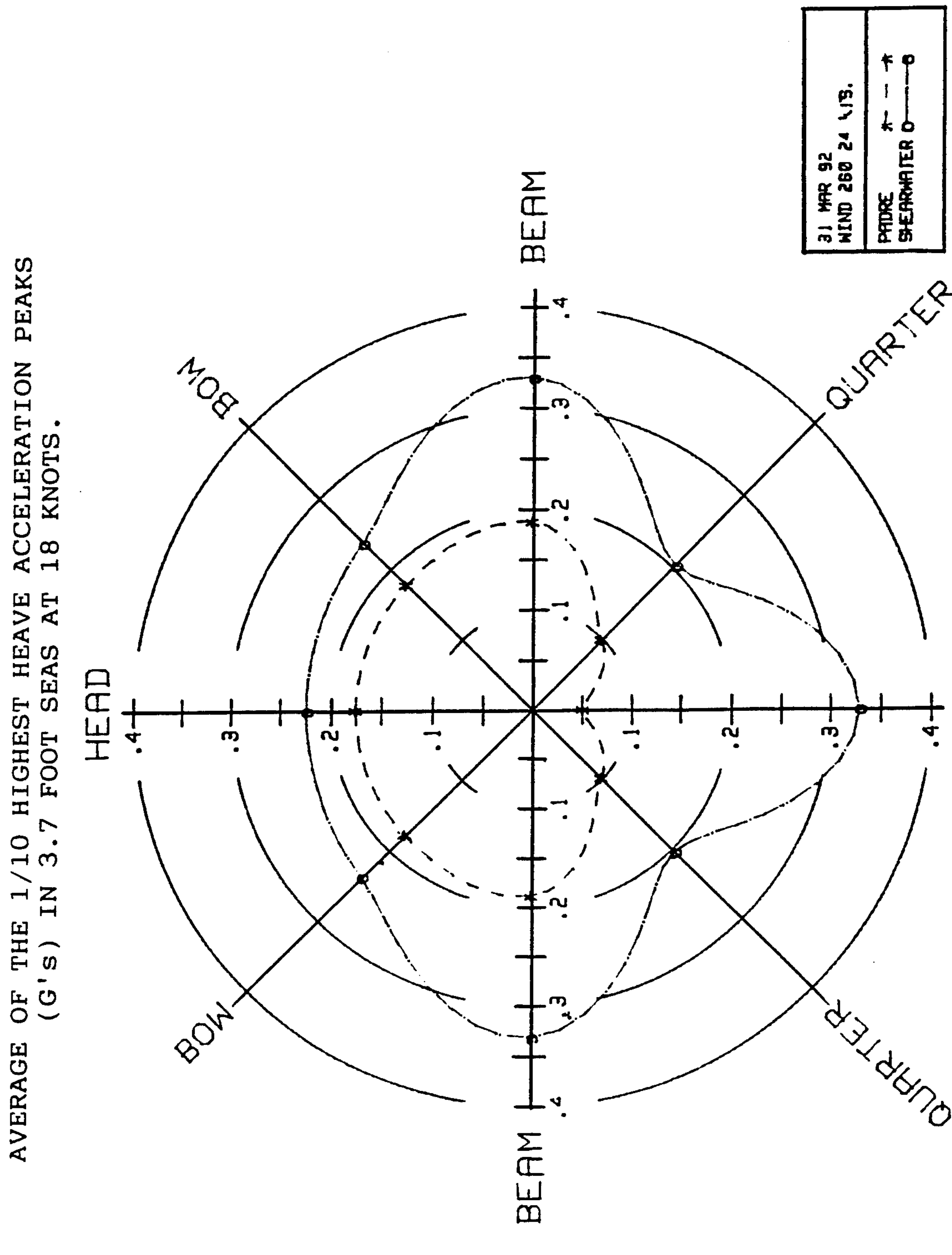

FIGURE 16. AVERAGE OF THE 1/10 HIGHEST HEAVE ACCELERATION PEAKS IN 3.7 FOOT SEAS AT 18 KNOTS.

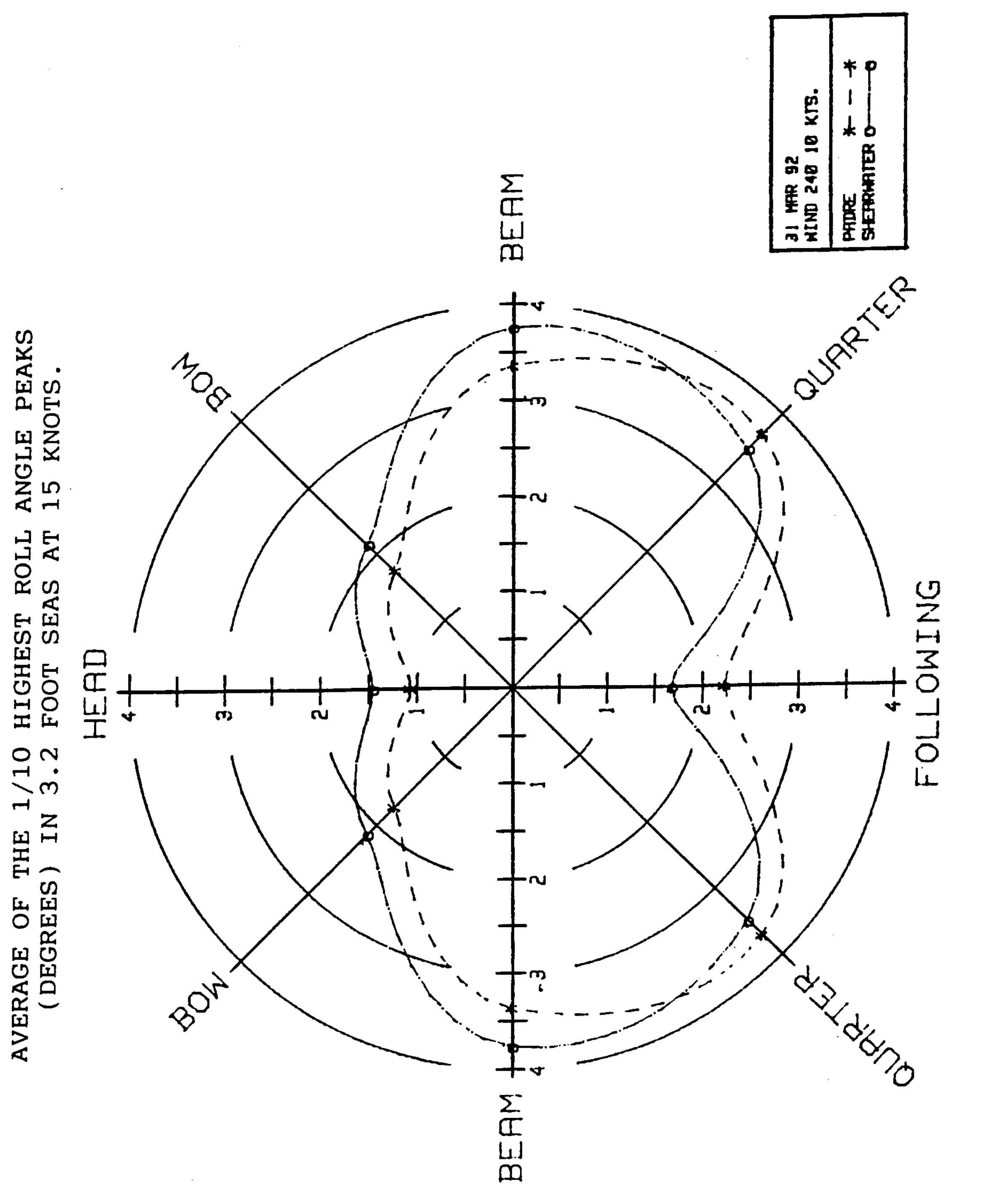

FIGURE 17. AVERAGE OF THE 1/10 HIGHEST ROLL ANGLE PEAKS IN 3.2 FOOT SEAS AT 15 KNOTS.

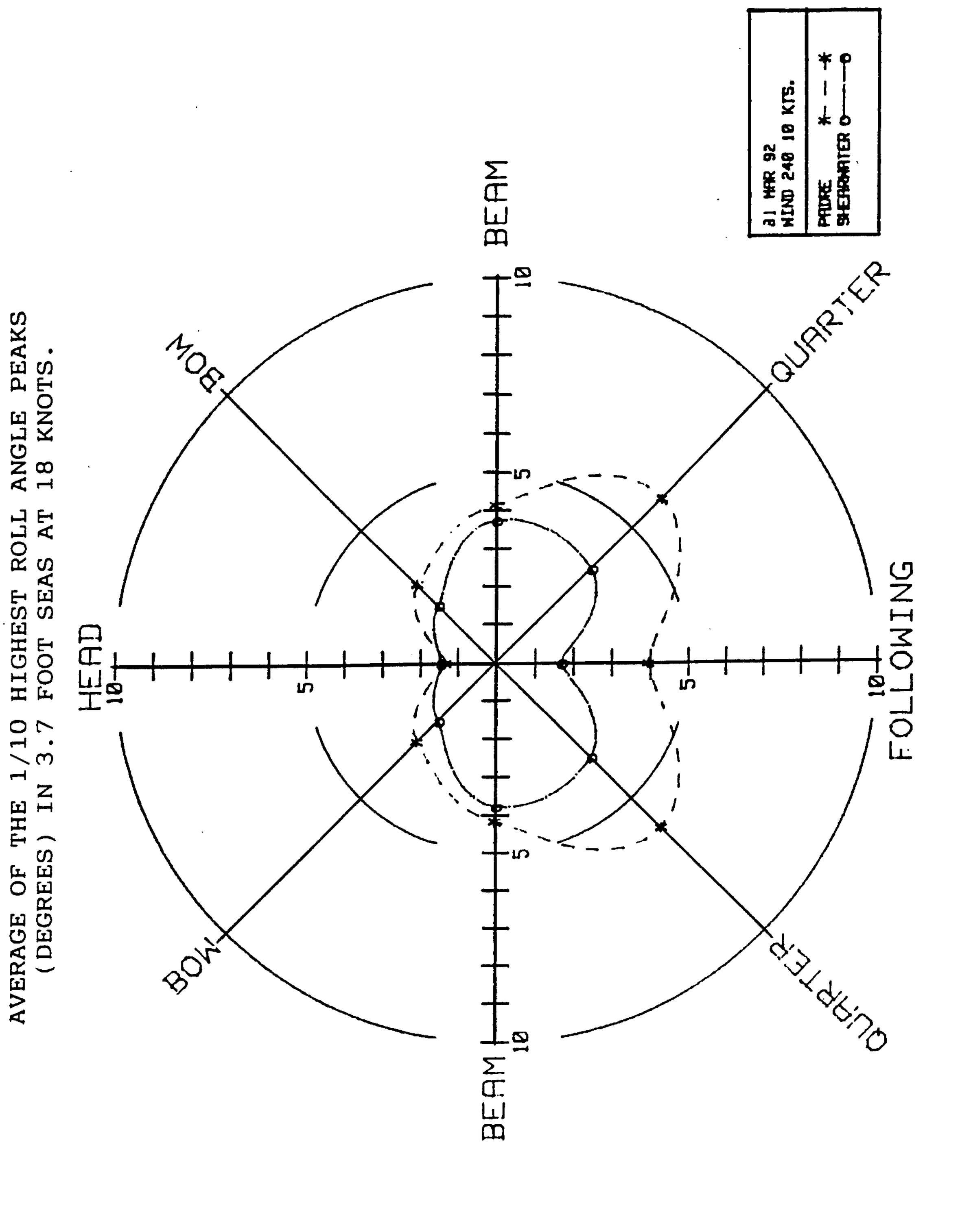

FIGURE 18. AVERAGE OF THE 1/10 HIGHEST ROLL ANGLE PEAKS IN 3.7 FOOT SEAS AT 18 KNOTS.

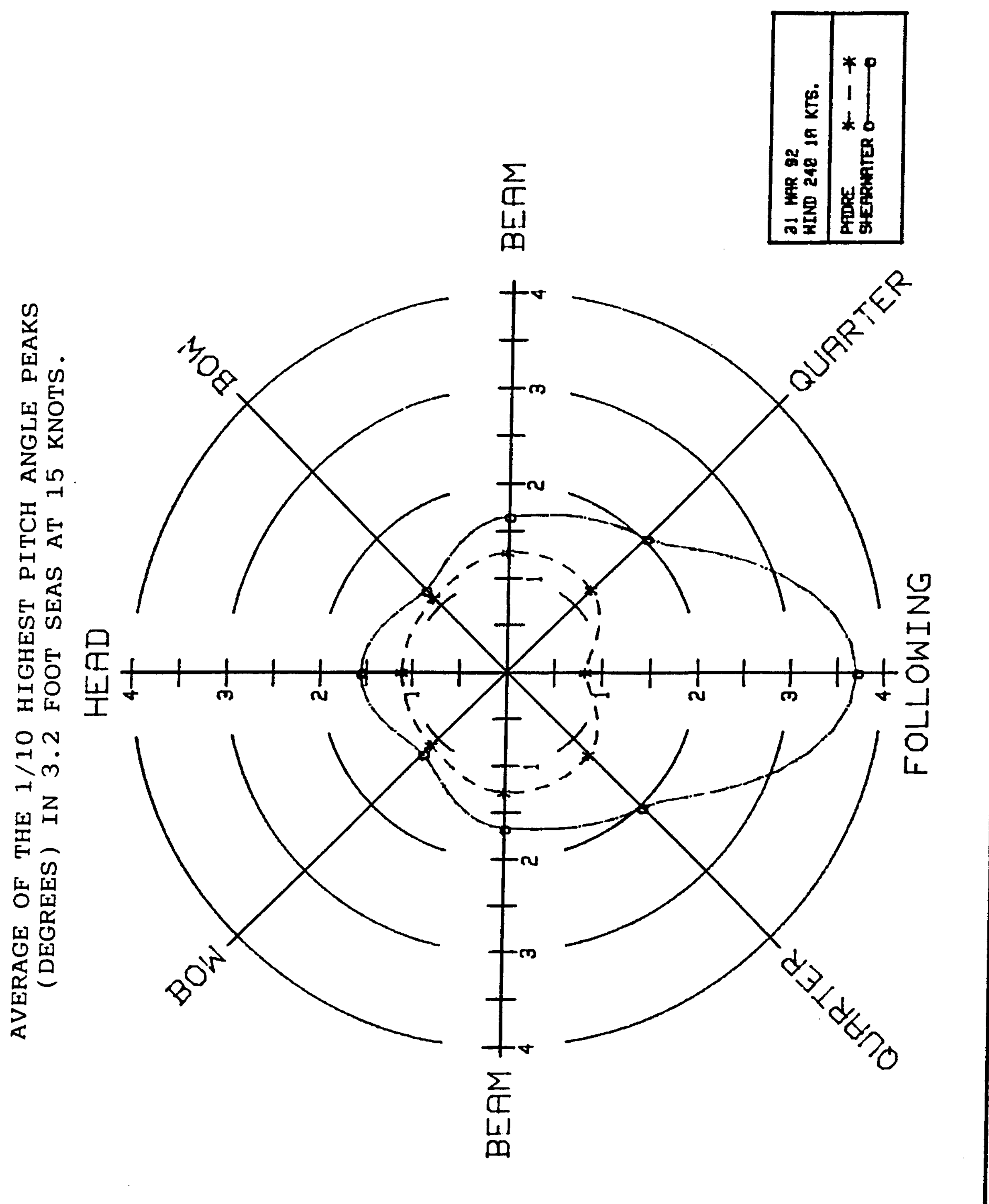

FIGURE 19. AVERAGE OF THE 1/10 HIGHEST PITCH ANGLE PEAKS IN 3.2 FOOT SEAS AT 15 KNOTS.

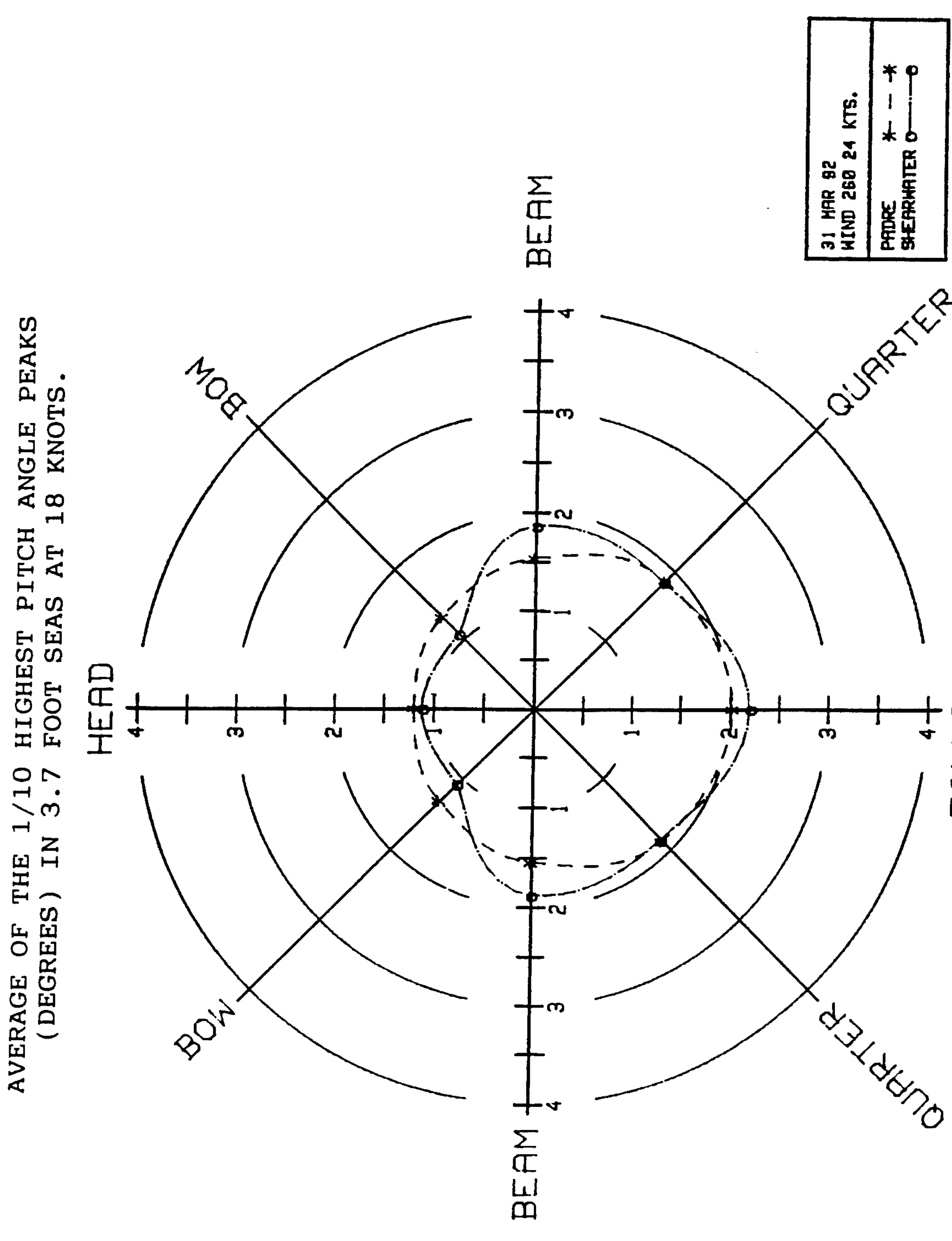

FIGURE 20. AVERAGE OF THE 1/10 HIGHEST PITCH ANGLE PEAKS IN 3.7 FOOT SEAS AT 18 KNOTS.

for the patrol boats first, at 15 knots, and then alternatively, at 18 knots. Figures 15 through 20 present plots of the AVERAGE OF THE 1/10 HIGHEST: HEAVE ACCELERATION, ROLL ANGLE AND PITCH ANGLE PEAKS for the patrol boats first, at 15 knots and then alternatively, at 18 knots. The definitions for these motion characteristics and the method used to obtain them are given in Appendix A.

All of the statistical data from these side-by-side underway tests are tabulated in Appendix B. This tabulation consists of the data plotted in Figures 9 through 20 plus all of the other data obtained from an analysis of the nine motion data tape channels.

DISCUSSION OF THE RESULTS

Wave Energy Density Spectra

The wave energy density spectrum measured on the morning of 31 March 1994 is shown in Figure 3. The significant wave height is 3.7 feet. It is assumed that this spectrum represents the sea state for the first two sets of tests: the side-by side tests with no way on, and the side-by-side tests conducted at 18 knots.

This is a narrow band spectrum. Most of the wave energy is concentrated between 0.1822 Hz and 0.2904 Hz. The modal frequency is 0.2109 Hz. The corresponding wave periods are 5.4885 sec., 3.4435 sec., and 4.7416 sec. The corresponding wave lengths and wave celerities, given by linear theory, are 154.2 ft., 60.7 ft., and 115.1 ft.; and 16.64 kts., 10.44 kts., and 14.37 kts. Note that the boats were outrunning the following seas for the tests at 18 knots.

The wave energy spectrum measured in the afternoon of 31 March 1994 is shown in Figure 4. The significant wave height is 3.2 feet. It is assumed that this spectrum represents the sea state for the third set of tests: the side-by-side tests conducted at 15 knots. There is less energy in this spectrum then in the morning spectrum. This probably indicates that the sea was dying as the day wore on.

This is a narrow band spectrum too. Most of the wave energy is concentrated between 0.2023 Hz and 0.2964 Hz. The modal frequency is 0.2383 Hz. The corresponding wave periods are 4.9432 sec., 3.3738 sec., and 4.1969 sec. The corresponding wave lengths and wave celerities, given by linear wave theory, are: 125.1 ft., 58.3 ft., and 90.2 ft.; and 14.99 kts., 10.23 kts., and 12.72 kts. Therefore, the boats were outrunning the shorter waves, and marginally outrunning the longer waves for the tests at 15 knots.

Tests With No Way On

Roll angle time histories for the USCGC PADRE and the USCGC SHEARWATER are given in Figures 5 and 6 for the side-by-side tests with no way on. The USCGC SHEARWATER was off cushion for the duration of this test.
Note that the USCGC PADRE experienced a roll angle amplitude build-up 50 seconds into the test which went from 5 degrees at 50 seconds to 20 degrees at 70 seconds, and then diminished. This roll build-up caused the captain of the USCGC PADRE to put way on in order to reduce the excursions in roll. The effect of putting way on manifests itself in the changing character of the time trace after about 100 seconds. There is no record of what he did, just a note to the effect that the test was terminated when the USCGC PADRE started to move.

The USCGC SHEARWATER also experienced random roll angle build-ups and diminutions during this test, but the maximum amplitude experienced was only about 6 degrees. The average of the 1/3 highest roll angle peaks experienced by the USCGC SHEARWATER was 3.4 degrees, while the average of the 1/3 highest roll angles experienced by the USCGC PADRE was 16.5 degrees. Obviously the surface effect ship gave a much better ride off cushion while drifting than the monohull.

In an attempt to explain the high roll angle build-up by the USCGC PADRE, a ship motions computer program, SMP'84 (7), was used to predict the motions of the boat. SMP'84 estimated the natural roll period of the USCGC PADRE to be 4.84 seconds. The corresponding natural roll frequency is 0.2066 Hz. Note that the applicable wave energy density spectrum discussed above had most of the wave energy concentrated for wave frequencies between 0.1822 Hz and 0.2904 Hz. The modal frequency was 0.2109 Hz. When a vessel is excited by random waves having frequencies in the neighborhood of its natural roll frequency, large roll angle build-ups are to be expected.

It should be pointed out that, although the USCGC PADRE is equipped with roll stabilizers, the stabilizers only become effective when the boat is underway at a reasonable speed, e.g. 10 to 15 knots.

Roll angle rate time histories for the USCGC PADRE and the USCGC SHEARWATER are given in Figures 7 and 8. The traces are somewhat more irregular than the traces for the roll angle time histories. As would be expected from the roll angle time histories, the roll angle rates for the USCGC PADRE are larger than those for the USCGC SHEARWATER.

Finally, note in Figure 5 that some of the roll angle data for the USCGC PADRE was lost 60 seconds into the test. The roll angle is building up to a peak when it abruptly drops to a trough at 60 seconds. Also note that the zero for Figure 7 appears to correspond to the neighborhood of 20 seconds in Figure 5.

Therefore, the roll angle rate time history between 30 and 50 seconds in Figure 7 corresponds roughly to the roll angle time history between 50 and 70 seconds in Figure 5. An examination of the roll angle rate time history for the boat, in Figure 7, reveals that the rate is continuously building up in amplitude between 30 and 50 seconds. Therefore, the roll angle should also be continuously building up between 50 and 70 seconds in Figure 5. This loss of roll angle data cannot be accounted for. It is important to avoid such losses in data because they produce errors in the statistics, and these in turn can lead to erroneous conclusions.

Tests With Way On

Polar coordinate plots of some of the significant results of the side-by-side tests conducted at 15 and 18 knots are presented in Figures 9 through 20. These plots allow a comparison of the seakeeping performance of the monohull (USCGC PADRE) and the SES (USCGC SHEARWATER) to be made at a glance. However, before proceeding with the comparison, let us consider the ship motions predictions which were made .

As stated above, the motions of the USCGC PADRE were predicted using the ship motions computer program SMP'84 (7). It should be pointed out that SMP'84 has two limitations that make a direct comparison of the computer prediction with the measured patrol boat motions data questionable. First, SMP'84 uses a Bretschneider, two parameter spectrum to characterize the seaway. SMP'84 has no provision to permit measured spectra to be input to the program. Therefore, the program cannot predict the response of a ship to a measured spectrum. Second, SMP'84 does not permit the action of the roll stabilizing fins to be modeled.

Never-the-less, by inputting a significant wave height and a modal frequency which are close to those of the measured spectra, two gross conclusions may be drawn. First, the computer predictions for a shortcrested sea were similar to the measured motions. The predictions for a longcrested sea were not, in general, as similar to the measured motions. Therefore, the seas were probably essentially shortcrested. This is also borne out by the measured roll motions in head and following seas, and the measured pitch motions in beam seas. Second, although the predicted motions were mostly larger than the measured motions, and sometimes vice versa, the predictions were of the same order of magnitude as the measured values. This is reassuring because the differences can be attributed, at least in part, to the differences in the spectra. This lends credibility to the measured data. Now let us return to the comparison of the motions of the monohull with those of the SES.

The average of the 1/3 highest heave acceleration peaks in 3.2 foot seas at 15 knots, and in 3.7 foot seas at 18 knots, are presented in Figures 9 and 10. Similar curves of the average of

the 1/10 highest acceleration peaks are plotted in Figures 15 and 16. The accelerations experienced by both boats are similar, but the monohull experiences significantly lower accelerations in following and quartering seas. SMP'84 also predicts much lower accelerations for the USCGC PADRE in following and quartering seas than in head, bow, and beam seas.

The average of the 1/3 highest roll angle peaks in 3.2 foot seas at 15 knots, and in 3.7 foot seas at 18 knots, are shown in Figures 11 and 12. Similar curves of the average of the 1/10 highest roll peaks are given in Figures 17 and 18. Note that the radial scale changes significantly in Figure 18. The remarkable thing about Figures 11, 12, 17, and part of Figure 18 is that both boats experience similar roll motions underway. This is in sharp contrast to the side-by-side tests with no way on. The roll stabilizers on the USCGC PADRE obviously become effective at 15 and 18 knots.

The average of the 1/10 highest roll angle peaks experienced by the USCGC PADRE are about double those experienced by the USCGC SHEARWATER in quartering and following seas in Figure 18. Since fewer (higher) occurrences are averaged in arriving at the average of the 1/10 highest roll angle peaks, than in arriving at the average of the 1/3 highest peaks, it may be that a few higher roll angles due to long wavelength following waves skewed the average of the 1/10 highest roll angle peaks. The orbital motion of the water in the long wavelength following waves would reduce the effectiveness of the roll stabilizing fins, and this may account for the measured difference shown in Figure 18.

The average of the 1/3 highest pitch angle peaks in 3.2 foot seas at 15 knots, and in 3.7 foot waves at 18 knots, are shown in Figures 13 and 14. Similar curves of the average of the 1/10 highest pitch angle peaks are plotted in Figures 19 and 20. The pitch angles experienced by both boats are very similar, with the exception of the following, and to some extent, the quartering sea cases at 15 knots. The SES experiences significantly larger pitch angles than the monohull for these cases. No explanation can be offered for this phenomenon.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS. First, there is very little difference between the motions of the USCGC PADRE, a monohull, and the USCGC SHEARWATER, an SES, while the boats are underway. However, bear in mind that this conclusion is based upon data obtained at medium speeds in relatively low sea states. The USCGC PADRE is marginally better, and this is probably due in no small part to the fact that the boat is equipped with roll stabilizers.

Second, there is a significant difference between the motions of the USCGC PADRE and the USCGC SHEARWATER while drifting. The USCGC PADRE rolls much more than the USCGC SHEARWATER while drifting. Since patrol boats often spend time drifting while on drug enforcement ELT patrols, this may be significant.

RECOMMENDATIONS. First, this was a very limited set of tests. If the opportunity presents itself in the future, it is recommended that additional side-by-side seakeeping tests of monohulls and SESs be conducted over a wider range of sea states.

Second, it is recommended that in the future, sea state data be taken on a Waverider buoy (or equivalent) for 20 minute periods, every half hour, for the duration of the tests. This will allow a better assessment of the sea conditions for the duration of the tests to be made.

Third, it is recommended that the data analysis package which includes the program GENPLT be reviewed, updated, and expanded to include a peak-to-trough analysis between zero crossings (See Appendix A).

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APPENDIX A

DATA REDUCTION USING GENPLT

The program GENPLT (6) was used to perform a statistical analysis of the data taken during the side-by-side seakeeping tests which form the subject of this report. This appendix will present a general description of how this program performed the analysis.

Exhibit A, on the following page, is a sample output page produced by the program. The first sixty seconds of roll angle data taken on board the USCGC SHEARWATER (WSES-3), in the side-by-side tests with no way on, was analyzed for the purpose of this example. Normally, the program would analyze a whole data run. For example, this would amount to twelve minutes of data for a run at 15 knots in beam seas.

The descriptive heading on the output page states that this is a roll angle analysis for the USCGC SHEARWATER, dead in the water, side-by-side, with the USCGC PADRE in March 1992 near Key West, Florida. It goes on to state that the calibration file SHEARDIW_C was used to convert the roll transducer voltages recorded on magnetic tape into roll angles in degrees. The calibration rate, "Calibration,"* was 12.5 degrees per volt.

Let us leave the descriptive heading for a moment, and shift our attention to the figure in the lower half of Exhibit A. This figure will give you a feeling for the nature of the data to be analyzed.

The figure contains a graph of the ROLL ANGLE, in degrees, versus TIME, in seconds, for the first minute of the test. The title of the figure corresponds to the descriptive heading at the top of the page. Note that the USCGC SHEARWATER appears to reach a -1.3 degree trough after one second, a +1.2 degree peak after 2.8 seconds, a -0.2 degree trough after 5.0 seconds, another 1.2 degree peak after 7.9 seconds, etc. All in all, the USCGC SHEARWATER appears to have experienced 28 peaks and troughs during the first minute of the test. We will now investigate whether or not these appearances agree with the results of the analysis performed by GENPLT.

Returning to the descriptive heading, we read that a total of 3600 roll angle data points were sampled for the analysis of one minute of data. The sampling rate was therefore 60 Hz. The heading goes on to state that 26 peaks were measured with respect to an "Offset" of -0.014 degrees. The Offset is the arithmetic mean value of the 3600 roll angle data points that were sampled for this example. It represents a statistical estimate of the

---

*Note: Capitalized words initially enclosed in quotation marks are variable names in the program GENPLT.

ROLL ANGLE (deg)

SDIW: SHEARWATER DEAD IN WATER SIDE BY SIDE PADRE 3/92 KW FL
CALIBRATION FILE USED: SHEARDIW_C
A TOTAL OF 3600 ROLL ANGLE (deg) DATA POINTS WERE ANALYZED.
26 PEAKS WERE MEASURED VS. THE -.014 OFFSET.

Average 1/10 highest	=	5.750
Average 1/3 highest	=	4.459
Root Mean Square	=	3.060
Mean Value	=	2.646
Standard Deviation	=	2.454
Highest Peak	=	6.124

Offset: -.014 (deg)
Calibration: 12.500
Epsilon: .250 (deg)

PEAKS:

6.124	5.376	4.976	4.111	4.014	3.801	3.649	3.649
3.624	3.549	3.239	3.176	3.026	2.874	2.524	2.524
1.976	1.874	1.764	1.599	1.474	1.426	1.199	1.199
.976	.964	.626	.474	.386			

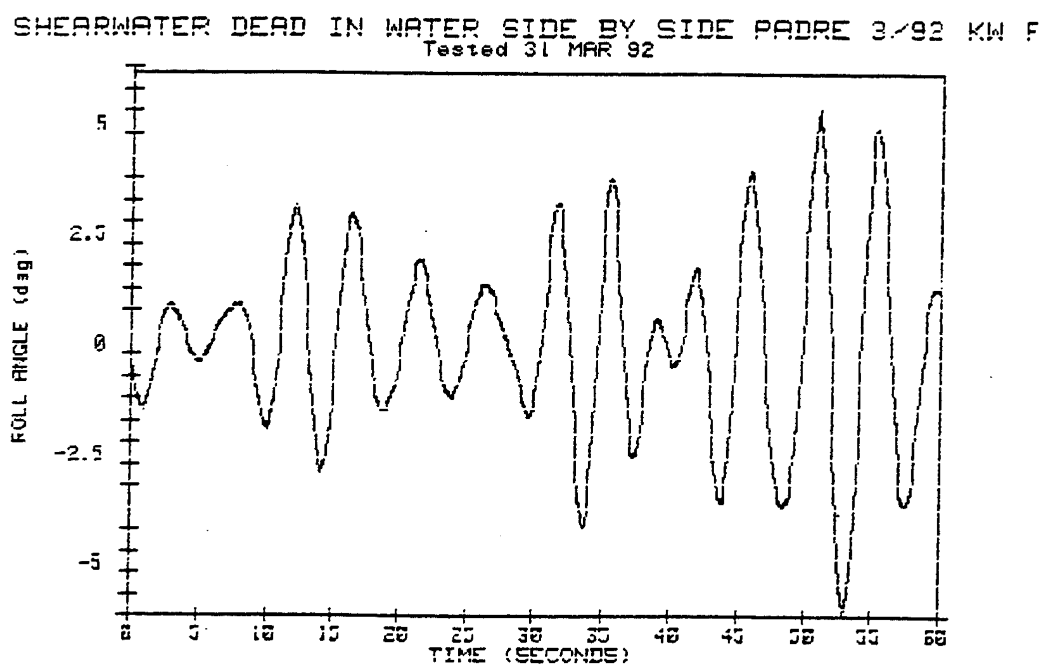

EXHIBIT A. A SAMPLE OUTPUT PAGE FROM THE PROGRAM GENPLT

mean roll angle experienced by the USCGC SHEARWATER during the first minute of this test, and it is used as a datum. We will now examine how GENPLT determines a "Peak".

In order to determine a Peak, the GENPLT program samples the roll data points sequentially looking for a crossing of the Offset line. The Offset line becomes the effective zero line for the purposes of data analysis. The program does this by examining the sign of each roll angle relative to the Offset, in turn, until it finds a change of sign. This change of sign would indicate either an up crossing, or a down crossing, of the Offset line on the graph. The program requires, in addition, that the absolute value of the latest data point relative to the Offset be greater than a predetermined constant Epsilon. Epsilon is equal to 0.250 degrees in this example. Epsilon is used as a noise filter, eliminating small Peaks in the neighborhood of the Offset line.

Once the program has determined the initial Offset crossing, it begins to search for a Peak. Note that since the first trough in the ROLL ANGLE versus TIME graph occurs before an Offset line crossing, this trough is not counted as a Peak.

The term Peak, in the program GENPLT, is synonymous with the maximum peak, or the minimum trough, between crossings of the Offset line in a time series of data which may have a number of maximum and minimum points in the neighborhood of the highest peak (highest maximum), or the lowest trough (lowest minimum).

Having found the data point that establishes the first Offset crossing, and the absolute value of this roll angle relative to the Offset, GENPLT stores this absolute value as the current "Highest" value. The program continues to sample the roll data sequentially, and determine the absolute value of the roll angle relative to the Offset. It continues to compare each new absolute value of the roll angle relative to the Offset with the current Highest value. If it is larger, it becomes the new Highest value. If not, the program goes on sampling and testing the data sequentially, until it either finds a new Highest value, or encounters a crossing of the Offset line.

At each step of the process, the sign of the new roll angle relative to the Offset is compared with the sign of the previous roll angle relative to the Offset. If the sign of the roll angle relative to the Offset changes, and if the Highest value is greater than Epsilon, then the current Highest value becomes a Peak. GENPLT also keeps track of the number of Peaks found. The process then repeats itself, following the same procedure it followed after it had found the first crossing of the Offset line.

The program continues determining Peaks until it runs out of data. Note that since a crossing of the Offset line is not encountered after the final peak on the graph in this example,

this peak is not countered as a Peak by GENPLT. Although the graph appears to have 28 peaks and troughs, GENPLT only finds 26 Peaks because it doesn't count the first apparent trough and the last apparent peak. This idiosyncrasy is exaggerated in this example. The effect is negligible in a 12 minute data run.

GENPLT now has a file containing all of the Peaks found. The program next sorts the Peaks in descending order of magnitude and begins the statistical analysis of the Peaks. The Peaks are tabulated in descending order, in rows and columns, above the figure in the lower half of Exhibit A. The eighth column is a repeat of the seventh column. This is an inexplicable idiosyncrasy of the program. There is no comment to explain why this was done.

The first statistic tabulated in Exhibit A is the "Average of the 1/10 highest" Peaks. This is determined in the following way.

> There are 26 Peaks. 26/10 = 2.6. This number is truncated at the decimal point, and GENPLT averages the first two Peaks.
>
> Average 1/10 highest = (6.124 + 5.376)/2 = 5.750.

The second statistic tabulated in Exhibit A is the "Average of the 1/3 highest" Peaks. This is determined in a similar fashion.

> There are 26 Peaks. 26/3 = 8.667. This number is truncated at the decimal point, and GENPLT averages the first eight Peaks.
>
> Average 1/3 highest = (6.124 + 5.376 + 4.976 + 4.111 + 4.014 + 3.801 + 3.649 + 3.624)/8
>
> = 4.459.

The third statistic tabulated in Exhibit A is the variable named, "Root Mean Square". This statistic is determined by taking the square root of the average of the sum of the squared values of the Peaks. The sum of the squared values of the Peaks in this example is 243.404. The average of the squared values is equal to 243.404/26, or 9.362. The square root of 9.362 is 3.060. Therefore,

> Root Mean Square = 3.060.

The fourth statistic is the "Mean Value". The Mean Value is the arithmetic mean of the Peaks. The sum of the Peaks in this example is 68.799. 68.799/26 = 2.646. Therefore,

> Mean Value = 2.646.

The fifth statistic is labled the "Standard Deviation". This is incorrect. The fifth statistic is actually the variance of the Peaks about the arithmetic mean of the peaks. It is a simple matter to verify this statistic on any moderately advanced scientific/engineering hand held calculator. Most calculators of this type have the capability of automatically calculating the average and standard deviation of a set of data. The standard deviation of the Peaks in this example is 1.567. The square of the standard deviation is the variance. The square of 1.567 is 2.454. Therefore,

The actual Standard Deviation = 1.567

The actual Varience = 2.454.

The sixth and final statistic is the "Highest Peak". A glance at the tabulated values of the Peaks on Exhibit A verifies that

Highest Peak = 6.124.

This concludes the simple explanation of how the statistics reported upon in this report were calculated.

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APPENDIX B

TABULATION OF THE DATA

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TABLE B-1a

CUTTER MOTIONS STATISTICS FOR THE USCGC PADRE (WPB 1328) IN SIDE-BY-SIDE TESTS WITH THE USCGC SHEARWATER (WSES 3) AT 15 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.2 FEET

Relative Sea Dir.	Type of Average	Roll Angle Degrees	Pitch Angle Degrees	Yaw Angle Degrees
Head	Highest	1.26	1.44	5.93
	1/10	1.06	1.11	3.69
	1/3	0.85	0.87	2.72
	Mean	0.58	0.61	1.52
Bow Qtr.	Highest	2.64	1.49	5.09
	1/10	1.74	1.10	2.99
	1/3	1.36	0.86	2.10
	Mean	0.88	0.60	1.19
Beam	Highest	5.01	1.68	6.54
	1/10	3.36	1.28	3.74
	1/3	2.68	1.03	2.14
	Mean	1.70	0.70	1.17
Stern Qtr.	Highest	4.44	1.52	10.94
	1/10	3.71	1.24	6.77
	1/3	2.87	1.01	3.37
	Mean	1.67	0.70	1.42
Foll.	Highest	2.35	0.90	9.35
	1/10	2.23	0.83	4.97
	1/3	1.82	0.71	2.72
	Mean	1.09	0.51	1.16

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-2a

CUTTER MOTIONS STATISTICS FOR THE USCGC PADRE (WPB 1328) IN SIDE-BY-SIDE TESTS WITH THE USCGC SHEARWATER (WSES 3) AT 18 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.7 FEET

Relative Sea Dir.	Type of Average	Roll Angle Degrees	Pitch Angle Degrees	Yaw Angle Degrees
Head	Highest	1.81	1.42	8.24
	1/10	1.31	1.20	3.34
	1/3	1.05	0.94	1.78
	Mean	0.71	0.62	0.91
Bow Qtr.	Highest	3.59	1.84	5.43
	1/10	2.92	1.32	3.69
	1/3	2.25	1.04	2.09
	Mean	1.38	0.68	1.02
Beam	Highest	5.99	1.89	6.65
	1/10	4.16	1.54	4.20
	1/3	3.15	1.24	2.26
	Mean	1.99	0.82	1.15
Stern Qtr.	Highest	9.90	2.40	14.70
	1/10	6.11	1.87	5.82
	1/3	4.68	1.37	2.96
	Mean	2.69	0.87	1.47
Foll.	Highest	5.02	2.05	12.28
	1/10	3.97	2.02	5.47
	1/3	3.16	1.54	3.04
	Mean	1.85	0.92	1.60

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-3a

CUTTER MOTIONS STATISTICS FOR THE USCGC SHEARWATER (WSES 3) IN SIDE-BY-SIDE TESTS WITH THE USCGC PADRE (WPB 1328) AT 15 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.2 FEET

Relative Sea Dir.	Type of Average	Roll Angle Degrees	Pitch Angle Degrees	Yaw Angle Degrees
Head	Highest	1.97	2.29	5.45
	1/10	1.46	1.56	2.45
	1/3	1.20	1.25	1.39
	Mean	0.79	0.82	0.76
Bow Qtr.	Highest	3.16	1.83	5.84
	1/10	2.14	1.23	3.44
	1/3	1.77	0.97	1.88
	Mean	1.13	0.66	0.92
Beam	Highest	5.17	2.50	4.17
	1/10	3.76	1.66	3.23
	1/3	2.96	1.34	1.77
	Mean	1.89	0.87	0.87
Stern Qtr.	Highest	4.87	2.57	7.72
	1/10	3.49	2.03	4.95
	1/3	2.79	1.64	2.76
	Mean	1.71	1.05	1.23
Foll.	Highest	2.21	6.11	5.10
	1/10	1.67	3.71	2.99
	1/3	1.38	1.97	1.75
	Mean	0.92	1.05	0.86

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-4a

CUTTER MOTIONS STATISTICS FOR THE USCGC SHEARWATER (WSES 3) IN SIDE-BY-SIDE TESTS WITH THE USCGC PADRE (WPB 1328) AT 18 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.7 FEET

Relative Sea Dir.	Type of Average	Roll Angle Degrees	Pitch Angle Degrees	Yaw Angle Degrees
Head	Highest	1.96	1.63	10.72
	1/10	1.48	1.12	2.77
	1/3	1.19	0.83	1.45
	Mean	0.82	0.54	0.72
Bow Qtr.	Highest	4.84	2.02	4.99
	1/10	3.48	1.08	2.52
	1/3	2.83	0.82	1.49
	Mean	1.75	0.56	0.75
Beam	Highest	8.45	2.46	-
	1/10	5.10	1.87	-
	1/3	4.03	1.45	-
	Mean	2.51	0.94	-
Stern Qtr.	Highest	7.61	2.55	6.08
	1/10	5.90	1.85	4.78
	1/3	4.71	1.38	3.57
	Mean	2.93	0.86	1.78
Foll.	Highest	5.74	2.41	6.88
	1/10	3.47	2.20	5.47
	1/3	2.70	1.80	3.41
	Mean	1.57	1.07	1.54

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

\- Note: The yaw angle data for the beam seas case is missing from the data tapes. It is likely that this data channel was lost for this leg of the side-by-side tests at 18 knots.

TABLE B-1b

CUTTER MOTIONS STATISTICS FOR THE USCGC PADRE (WPB 1328) IN SIDE-BY-SIDE TESTS WITH THE USCGC SHEARWATER (WSES 3) AT 15 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.2 FEET

Relative Sea Dir.	Type of Average	Roll Rate Deg/Sec	Pitch Rate Deg/Sec	Yaw Rate Deg/Sec
Head	Highest	2.17	4.40	1.70
	1/10	1.65	3.08	1.24
	1/3	1.29	2.45	0.99
	Mean	0.82	1.77	0.62
Bow Qtr.	Highest	3.06	4.54	1.93
	1/10	2.21	2.78	1.52
	1/3	1.79	2.23	1.24
	Mean	1.13	1.58	0.77
Beam	Highest	7.31	3.84	2.57
	1/10	4.19	2.73	1.97
	1/3	3.06	2.22	1.67
	Mean	1.92	1.60	1.06
Stern Qtr.	Highest	2.66	1.84	3.20
	1/10	2.37	1.48	2.54
	1/3	2.00	1.27	2.06
	Mean	1.25	0.86	1.27
Foll.	Highest	1.78	1.51	1.80
	1/10	1.30	1.31	1.66
	1/3	0.98	1.10	1.41
	Mean	0.62	0.76	0.83

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-2b

CUTTER MOTIONS STATISTICS FOR THE USCGC PADRE (WPB 1328) IN SIDE-BY-SIDE TESTS WITH THE USCGC SHEARWATER (WSES 3) AT 18 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.7 FEET

Relative Sea Dir.	Type of Average	Roll Rate Deg/Sec	Pitch Rate Deg/Sec	Yaw Rate Deg/Sec
Head	Highest	2.66	4.64	2.05
	1/10	2.06	3.31	1.53
	1/3	1.66	2.51	1.24
	Mean	1.01	1.72	0.79
Bow Qtr.	Highest	4.79	4.59	2.77
	1/10	3.18	3.44	1.85
	1/3	2.54	2.60	1.50
	Mean	1.75	1.80	0.93
Beam	Highest	5.79	4.70	2.22
	1/10	4.34	3.49	1.97
	1/3	3.31	2.71	1.67
	Mean	2.17	1.83	1.05
Stern Qtr.	Highest	6.49	3.01	3.60
	1/10	5.16	1.90	2.80
	1/3	3.79	1.57	2.16
	Mean	2.32	1.04	1.25
Foll.	Highest	3.89	2.16	2.77
	1/10	2.60	1.56	2.20
	1/3	2.09	1.27	1.83
	Mean	1.25	0.82	1.21

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-3b

CUTTER MOTIONS STATISTICS FOR THE USCGC SHEARWATER (WSES 3) IN SIDE-BY-SIDE TESTS WITH THE USCGC PADRE (WPB 1328) AT 15 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.2 FEET

Relative Sea Dir.	Type of Average	Roll Rate Deg/Sec	Pitch Rate Deg/Sec	Yaw Rate Deg/Sec
Head	Highest	4.88	3.96	1.63
	1/10	3.44	2.81	0.83
	1/3	2.75	2.32	0.65
	Mean	1.82	1.64	0.41
Bow Qtr.	Highest	6.87	3.12	1.44
	1/10	4.93	2.31	0.95
	1/3	3.88	1.92	0.74
	Mean	2.43	1.38	0.44
Beam	Highest	9.16	3.14	1.46
	1/10	7.24	2.52	1.13
	1/3	6.11	2.12	0.90
	Mean	4.05	1.58	0.55
Stern Qtr.	Highest	7.94	2.02	2.09
	1/10	5.08	1.66	1.79
	1/3	4.03	1.35	1.33
	Mean	2.57	0.91	0.80
Foll.	Highest	3.87	1.89	1.33
	1/10	2.87	1.42	1.09
	1/3	2.27	1.17	0.83
	Mean	1.55	0.77	0.50

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-4b

CUTTER MOTIONS STATISTICS FOR THE USCGC SHEARWATER (WSES 3) IN SIDE-BY-SIDE TESTS WITH THE USCGC PADRE (WPB 1328) AT 18 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.7 FEET

Relative Sea Dir.	Type of Average	Roll Rate Deg/Sec	Pitch Rate Deg/Sec	Yaw Rate Deg/Sec
Head	Highest	4.52	3.24	1.70
	1/10	3.23	2.32	0.95
	1/3	2.53	1.91	0.72
	Mean	1.47	1.41	0.43
Bow Qtr.	Highest	9.71	2.94	1.80
	1/10	6.26	2.23	1.41
	1/3	4.94	1.83	1.07
	Mean	2.73	1.34	0.68
Beam	Highest	14.33	3.64	2.70
	1/10	8.62	2.99	2.11
	1/3	7.07	2.48	1.61
	Mean	4.63	1.75	0.99
Stern Qtr.	Highest	10.31	2.86	2.49
	1/10	8.70	2.00	2.17
	1/3	7.00	1.64	1.80
	Mean	4.31	1.12	1.08
Foll.	Highest	7.30	2.32	2.53
	1/10	4.10	1.88	1.90
	1/3	3.22	1.54	1.49
	Mean	2.02	1.06	0.92

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-1c

CUTTER MOTIONS STATISTICS FOR THE USCGC PADRE (WPB 1328) IN SIDE-BY-SIDE TESTS WITH THE USCGC SHEARWATER (WSES 3) AT 15 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.2 FEET

Relative Sea Dir.	Type of Average	Heave Acceleration (G's)	Surge Acceleration (G's)	Sway Acceleration (G's)
Head	Highest	0.192	0.022	0.034
	1/10	0.153	0.019	0.027
	1/3	0.123	0.016	0.022
	Mean	0.090	0.013	0.017
Bow Qtr.	Highest	0.248	0.022	0.053
	1/10	0.152	0.019	0.036
	1/3	0.122	0.017	0.029
	Mean	0.088	0.014	0.021
Beam	Highest	0.214	0.027	0.097
	1/10	0.168	0.026	0.062
	1/3	0.137	0.022	0.048
	Mean	0.099	0.017	0.031
Stern Qtr.	Highest	0.027	0.027	0.052
	1/10	0.024	0.026	0.041
	1/3	0.020	0.022	0.033
	Mean	0.013	0.016	0.022
Foll.	Highest	0.062	0.021	0.028
	1/10	0.042	0.016	0.028
	1/3	0.034	0.013	0.025
	Mean	0.024	0.010	0.019

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-2c

CUTTER MOTIONS STATISTICS FOR THE USCGC PADRE (WPB 1328) IN SIDE-BY-SIDE TESTS WITH THE USCGC SHEARWATER (WSES 3) AT 18 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.7 FEET

Relative Sea Dir.	Type of Average	Heave Acceleration (G's)	Surge Acceleration (G's)	Sway Acceleration (G's)
Head	Highest	0.214	0.033	0.055
	1/10	0.175	0.024	0.033
	1/3	0.137	0.019	0.026
	Mean	0.096	0.015	0.019
Bow Qtr.	Highest	0.242	0.031	0.055
	1/10	0.178	0.024	0.045
	1/3	0.141	0.020	0.036
	Mean	0.099	0.016	0.025
Beam	Highest	0.237	0.031	0.069
	1/10	0.188	0.026	0.058
	1/3	0.154	0.023	0.045
	Mean	0.108	0.018	0.031
Stern Qtr.	Highest	0.143	0.042	0.084
	1/10	0.099	0.036	0.058
	1/3	0.076	0.027	0.047
	Mean	0.049	0.017	0.032
Foll.	Highest	0.086	0.044	0.047
	1/10	0.051	0.031	0.041
	1/3	0.038	0.023	0.034
	Mean	0.023	0.015	0.024

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-3c

CUTTER MOTIONS STATISTICS FOR THE USCGC SHEARWATER (WSES 3) IN SIDE-BY-SIDE TESTS WITH THE USCGC PADRE (WPB 1328) AT 15 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.2 FEET

Relative Sea Dir.	Type of Average	Heave Acceleration (G's)	Surge Acceleration (G's)	Sway Acceleration (G's)
Head	Highest	0.205	0.068	0.047
	1/10	0.154	0.037	0.037
	1/3	0.125	0.030	0.029
	Mean	0.091	0.021	0.021
Bow Qtr.	Highest	0.230	0.053	0.049
	1/10	0.152	0.035	0.039
	1/3	0.123	0.028	0.033
	Mean	0.090	0.020	0.023
Beam	Highest	0.170	0.054	0.077
	1/10	0.134	0.038	0.060
	1/3	0.115	0.031	0.047
	Mean	0.087	0.021	0.031
Stern Qtr.	Highest	0.172	0.055	0.041
	1/10	0.131	0.042	0.034
	1/3	0.096	0.033	0.028
	Mean	0.071	0.022	0.020
Foll.	Highest	0.107	0.045	0.026
	1/10	0.103	0.037	0.023
	1/3	0.088	0.029	0.020
	Mean	0.069	0.019	0.016

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.

TABLE B-4c

CUTTER MOTIONS STATISTICS FOR THE USCGC SHEARWATER (WSES 3) IN SIDE-BY-SIDE TESTS WITH THE USCGC PADRE (WPB 1328) AT 18 KNOTS IN A SEA WHERE THE AVERAGE OF THE 1/3 HIGHEST WAVE PEAKS* WAS 3.7 FEET

Relative Sea Dir.	Type of Average	Heave Acceleration (G's)	Surge Acceleration (G's)	Sway Acceleration (G's)
Head	Highest	0.446	0.052	0.051
	1/10	0.224	0.035	0.036
	1/3	0.179	0.029	0.030
	Mean	0.124	0.021	0.021
Bow Qtr.	Highest	0.364	0.057	0.067
	1/10	0.238	0.037	0.050
	1/3	0.189	0.030	0.040
	Mean	0.127	0.021	0.027
Beam	Highest	0.786	0.061	0.111
	1/10	0.331	0.044	0.072
	1/3	0.217	0.035	0.056
	Mean	0.136	0.023	0.037
Stern Qtr.	Highest	0.346	0.055	0.083
	1/10	0.204	0.042	0.062
	1/3	0.142	0.033	0.051
	Mean	0.096	0.021	0.033
Foll.	Highest	0.527	0.056	0.045
	1/10	0.329	0.042	0.035
	1/3	0.200	0.033	0.028
	Mean	0.113	0.022	0.020

* Note: See APPENDIX A for an explanation of how this and the other statistics were obtained.